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13. ABSTRACT *(Maximum 200 words)*

This contract was a continuation of earlier contracts for the Army Center of Excellence in Mathematical Sciences established in January 1986. The Mathematical Sciences Institute provided a center of focus of the continuation of development of mathematics in the traditional areas, and more importantly, the extension of research into new areas with the development of new directions for mathematics.

The philosophy behind a center for mathematical research is that only a center has the capacity to meet cross-disciplinary challenges which must combine talents of computer scientist, mathematicians, scientists, and engineers. A center can be used to create a positive national climate for the development of an entire subject by providing a forum of interaction to create a national community of researchers. A center with flexible funding and insightful leadership can identify and nurture emerging research areas which have high risk of failure but high potential of return. The Mathematical Sciences Institute has provided this leadership and flexibility to meet the changes in mathematical science as technology and knowledge expands.

The proposal maintained the Mathematical Sciences Institute as the overall center for administration and program direction, with the responsibility to oversee three smaller Centers of Excellence in the Mathematical Sciences for: Nonlinear Analysis, Stochastic Analysis, and Symbolic Methods in Algorithmic Mathematics. Each of these centers pursued advancements in their areas but also coordinated and collaborated between centers. This model was extremely successful. And, as funding levels changed it was possible to allocate available resources to those programs exhibiting the greatest potential. During the over ten years of operations, the Mathematical Sciences Institute proved the value of such centers and gained an international reputation as "the" center for mathematical excellence.

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13. ABSTRACT (Maximum 200 words)

We present a preliminary design of a hardware architecture for computing initial segments of primitive recursive functions and iterative processes. The formulation of the architecture is based in a paradigm which proposes a procedure for (1). encoding a function or process and, (2) carrying ou the computation. The paradigm is firmly rooted in the formalism of quantum mechanics. We propose as our representation of the architecture a generic regular multiparticle, two-dimensional lattice. This lattice is a model of crystal structures that in principle, can be produced in the lab today.

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Kohn-Nerode Quantum Computing Program

Final Progress Report

By

Anil Nerode

and

Wolf Kohn

U.S. Army Research Office
Sub-contract Under
DAAL03-91-C-0027

Cornell University

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Problem Statement

This document describes ongoing research for the formulation, analysis and implementation of a programmable device, termed Quantum Function Evaluator (QFE), that uses quantum state propagation as a paradigm for computing objects of a class I of functions herein referred to as the computable class. The proposed research is divided into three phases: *Formulation, Evaluation* and *Implementation.* We will discuss an outline of the first phase in the next sections.

Outline of formulation Phase

Over a period of several years, Kohn and Nerode have conducted joint and independent research to explore formal methods in Hybrid System Theories [1], [2], [3], [4], [5], [6], [7] to determine effective computational procedures for generating control laws in a variety of application domains. The quantum computing paradigm and its possible implementation proposed for this research effort, constitute a significant extension of the results in our early efforts. This outline provides a brief synopsis of our proposed paradigm and a preliminary sketch of a possible implementation architecture. The Formulation phase of our study is composed of two major tasks: the detailed specification of the proposed *paradigm* and the detailed specification of an *implementation architecture*. We will outline the major features of these two items next.

Paradigm

The main aspects of our proposed paradigm are summarized in Figure 1. The proposed computational paradigm is composed of seven sequential steps. We outline their functionality next.

Input Function: Each Input Function is either a map of the form:

$$f : S_1 \times \cdots \times S_N \rightarrow D$$

where S_i, $i = 1, ..., N$ and D are finite subsets of the naturals of the form:

$$S_i = \{0, \cdots, N_i\}$$
$$D = \{0, \cdots, N_d\}$$

or a solution of an iterative process of the form:

$$y^i_{n+1} = f^i\left(y^1_n, \ldots, y^k_n\right), \; i = 1, \ldots, k$$

with

$$f^i : S^k \rightarrow S, \; S = \{0, 1, \ldots, N_S\}$$

Let p be the natural number defined by:

$$p = \max_{i,d}\left\{\{N_i, \, i = 1, \ldots, N\}, N_d\right\}$$

Then, we can express f by the *encoding*:

$$F : \left[0, 1, \ldots, p^{N-1}\right] \rightarrow [0, 1, \ldots, p]$$

$$\text{For} \quad x = \sum_{s=0}^{N-1} n_s \cdot p^{N-1-s} \tag{1}$$

$$F(x) = \begin{cases} f\left(n_0, \ldots, n_{N-1}\right), & \text{If defined} \\ 0 & \text{Otherwise} \end{cases}$$

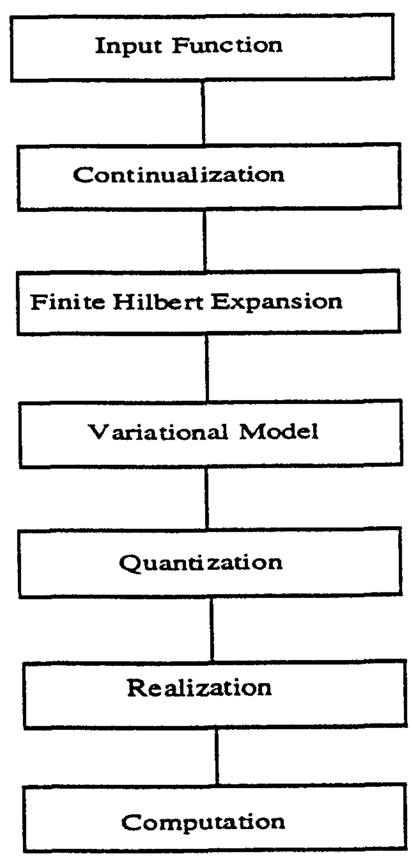

Figure 1. Quantum Computing Paradigm

Thus, the encoding is a discrete function with domain on certain points of the real line, taking values in a subset of points of the real line coinciding with the values in the range of f and mapping to 0 any encoding x that corresponds to a tuple not in the domain of f.

The central objective behind our paradigm is to find effective and fast means to compute discrete finite-valued functions via *Quantum Approximations* to their encoding. We will characterize the nature of these approximations later on. We conclude the overview of the Input Function element of our paradigm with a formal definition of the class I of computable functions.

The class I of computable input functions is defined as follows:

(i) I contains all the functions encodable in one step as above.

(ii) If $\{f_1, \cdots, f_K, f_i : S_1 \times \cdots \times S_N \rightarrow S_{N+1}$, K finite, $S_i = \{1, ..., N_i, N_i$, finite $\}\}$ is a subset of I, so is their direct sum: $f_1 \oplus \cdots \oplus f_K : S_1 \times \cdots \times S_N \rightarrow S^K_{N+1}$.

(iii) I contains the projection functions:
$p_i : S_1 \times \cdots \times S_N \rightarrow S_i$, $p_i(n_1, ..., n_i, ..., n_N) = n_i$.

(iv) If $\{f_1, \cdots, f_K, f_i : S_1 \times \cdots \times S_N \rightarrow S_{N+1}$, K finite, $S_i = \{1, ..., N_i, N_i$, finite $\}\}$ is a subset of I and $g : S^K_{N+1} \rightarrow S_{N+1}$ is in I, so is the composition: $g(f_1, \cdots, f_K) : S_1 \times \cdots \times S_N \rightarrow S_{N+1}$.

(v) If for each $n \in \mathrm{N}$, $g : \mathrm{N} \times S_1 \times \cdots \times S_K \rightarrow \mathrm{N}$ is in I so is $\min\{n, g(n, n_1, \cdots, n_K) = 0\}$.

(vi) If $g : \mathrm{N} \times S_K \rightarrow S_K$ is in I, then the family of functions,
$\{f : \mathrm{N} \times S_1 \times \cdots \times S_K \rightarrow S_{K+1}, f(n+1, n_1, ..., n_k) = g(n, f(n, n_1, ..., n_k))\}$ is in I.

(vii) Any function constructed by the finite application of (i)-(vi) is in I.

We note that the defining characteristic of I is that its elements are either an encoding or can be transformed into an encoding via finite number of steps (ii)- (vii) above. We conclude the outline of the input function with the following observation: although the class I of computable functions I includes only completely specified functions, it can be extended to a larger class which include discrete partially specified functions (relations). We will discuss this extension in a future report.

Continualization: We can complete the encoding function F into a *step function* Φ with the following identity:

$$\begin{aligned} &\Phi : [0, p^{N-1}) \rightarrow [0, p^{N-1}) \\ &\Phi(y) = F(x), \quad \text{for each } y, \ y \in [x, x+1), \ x \in \{0, ..., p^{N-1}\} \end{aligned} \tag{2}$$

Figure 2 illustrates this identity for the encoding of the function given in Table 1. We refer to the process of constructing Φ as *Continualization*. With some needed modifications, this continualization process can be extended to discrete functions that are specified as solutions of iterations of the form:

Table 1.

n_0	n_1	f
0	0	2
0	1	1
0	2	1
1	0	0
1	1	2
1	2	2
2	0	1
2	1	0
2	2	0

Original Function

x	F
0	2
1	1
2	1
3	0
4	2
5	2
6	1
7	0
8	0

Encoding

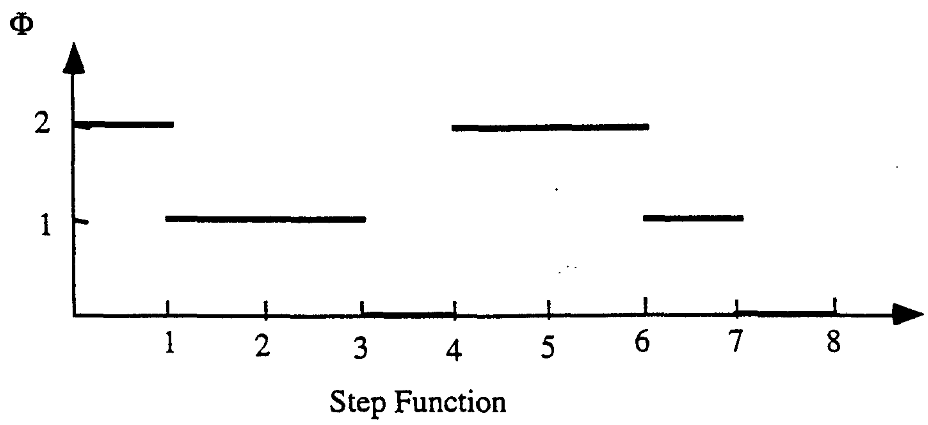

Figure 2. Continualization of a function

$$Z_{k+1} = g(Z_k, k)$$

with (3)

$$Z_k \in S^N, \ S = \{0, ..., N, N \text{ finite}\} \text{ for each k, k an integer}$$

Following Kushner and Clark [8], the encoding and continualization of a process of the form of (3) leads to a differential equation of the form of (4) together with a sampling rule of the form of (5):

$$\dot{x}(t) = G(x(t), t) + B(t) \tag{4}$$

$$G(\cdot, t) = \quad \text{continualized version of } g(\cdot, k),\ t \in [k\Delta, (k+1)\Delta),\ k \in N \tag{5}$$

and B(t) is a 'convergence' function satisfying the following conditions:
B is bounded, and B(t) goes to zero as $t \to \infty$ quadratically. Under general conditions, one can show [9] that particular solutions of (4) are asymptotically stable in the sense of Lyapunov. In (5), Δ is a scaling parameter chosen to transform the iteration variable k into the time variable t.

Finite Hilbert Expansion: The continualized functions, appearing in (1) or (4) may be expanded in a discrete Hilbert space γ_p in terms of an orthogonal basis set such as the set of p-valued Chrestenton functions. The general form of a Chrestenton basis function is given below.

$$\text{Chrestenton function: } \varphi^j(x) = \exp\left(\frac{2\pi}{p}\, i \sum_{s=0}^{N-1} j_{(N-1-s)} \cdot x_s\right)$$

$$\text{with } j = \sum_{s=0}^{N-1} j_s \cdot p^{N-1-s}, \quad x = \sum_{s=0}^{N-1} x_s \cdot p^{N-1-s}$$

For the sake of simplicity, we will continue our discussion here under the assumption that the selected bases are the Chrestenton functions, although during the study of *tunneling* as a mechanism for implementing *quantum oracles* we may need to switch to other bases.

Let $B_p = \{\varphi^k \mid \varphi^k : [0, p^{N-1}] \to [0, p^{N-1}],\ k = 0, \cdots, p^N - 1\}$ be an orthogonal basis for γ_p. That is, $\int \varphi^k(x) \cdot \overline{\varphi}^l(x) dx = c \cdot \delta_{k,l}$ for each k, l in $\{0, \cdots, p^N - 1\}$. The function F can be expanded in terms of B_p as follows:

$$\Phi(x) = \sum_{x \in [0,p]^N} \beta_k \cdot \varphi^k(x) \tag{6}$$

with

$$\beta_k = \int_0^{p^N} \Phi(x) \cdot \overline{\varphi}^k(x) \cdot dx \Big/ \int_0^{p^N} \varphi^k(x) \cdot \overline{\varphi}^k(x) \cdot dx$$

We note that if we know the spectrum $\{\beta_k\}$ We can easily compute Φ, via (1), extract the encoding F from it and from F determine the original function f. However even for functions of more than academic interest, the number of terms in the spectrum runs in the range of 10^5 to 10^{12}. The central idea, in this regard, is that we can find very close approximations to this evaluation by a *hardware quantum device,* which we will discuss in the next section. For the moment, in this section, we continue with the description of the paradigm.

Variational Model: Given a computational process to be carried out, expressed in the form of the differential equation (4), we want to formulate the computation of the solution x(t), as a variational problem. Our purpose is to proceed from this to obtain a quantum mechanical "program " for computing the solution. For the purposes of this report, we will describe the variational formulation formally. Mathematical rigor will follow in future reports.

The variational formulation is of the form:

$$\min_x \int L(x, \dot{x}, t) \cdot dt \tag{7}$$

where L known, as the lagrangian function, is chosen so that for specific boundary conditions the solutions of (7) and (4) coincide. For the purposes of our procedure we assume that L is three times continuously differentiable in its arguments. We now proceed to describe how L is determined from the function G, constructed earlier. Towards this objective we write the necessary conditions for optimality in (7), The Euler Lagrange conditions. They are expressed by the following second order differential equation:

$$\dot{x}L_{\dot{x}x} + \ddot{x}\,L_{\dot{x}\dot{x}} + L_{\dot{x}t} - L_x = 0 \tag{8}$$

Here and in the derivations that follow subindices indicate partial derivatives.

Differentiating (4) with respect to t, to obtain a definition for $\ddot{x}$, replacing in (8), and differentiating the result with respect to $\dot{x}$, we obtain, after some algebra, the following partial differential equation :

$$L_{\dot{x}\dot{x}t} + G_x L_{\dot{x}\dot{x}} + \dot{x}L_{\dot{x}\dot{x}x} + \left(\dot{x}G_x + G_t + B_t\right)L_{\dot{x}\dot{x}\dot{x}} = 0 \tag{9}$$

Let

$$q(x, \dot{x}, t) = L_{\dot{x}\dot{x}}(x, \dot{x}, t) \tag{10}$$

In terms of q, (9) takes the form,

$$q_t + G_x q + \dot{x}q_x + \left(\dot{x}G_x + G_t + B_t\right)q_{\dot{x}} = 0 \tag{11}$$

That is, q satisfies a linear hyperbolic equation, whose solution can be computed by the method of characteristics ([10]). Once a solution for q is obtained L can be determined from (10) by a double quadrature. In summary, given (4) we construct by the procedure sketched above the corresponding lagrangian.

Quantization: In order to quantize the program described by (7), one introduces the canonical conjugate variables: generalized position and momentum [12]. In the canonical Quantization these are chosen as follows: position variable, representing the position operator, is represented by x, and the momentum variable is chosen as:

$$p = L_{\dot{x}} \tag{12}$$

The components of x, p satisfy the canonical commutation relations:

$$[x_k, p_l] = i\delta_{k,l} \quad k, l = 1, \ldots, N \tag{13}$$

Next, we define the Hamiltonian of the system as follows:

$$H(x, p) = \sum p_k \cdot \dot{x}_k - L \tag{14}$$

The equation of motion of the system representing the program to be executed is then the Schödinger equation given by :

$$i\hbar \frac{\partial}{\partial t}|\Psi(t)\rangle = H\left(x, \frac{1}{i}\frac{\partial}{\partial x}\right)|\Psi(t)\rangle \tag{15}$$

Realization: Assume that a physical system, the hardware, is available to us. This system is characterized by the Hamiltonian operator H_0. The realization step consists in ***engineering*** a field Hamiltonian H_f such that the hardware, when interacting with this field satisfies the following condition:

$$|H_0 + H_f - H| \leq \varepsilon \tag{16}$$

where $|\cdot|$ denotes a suitably selected operator norm and ε is an engineering parameter chosen to satisfy precision requirements for the computation.

The general idea is that the *discrete spectrum* of the composite Hamiltonian $H_0 + H_f$ approximates the spectrum of the function or process being computed (see (6) above). Precisely, we will devote our next report to prove the following result:

"*Let*

$\{\lambda_k,\ k = 1, \ldots, N\}$ be a subset of the eigenvalues of $H_0 + H_f$ with corresponding eigenvectors $\{\Psi_k\ k = 1, \ldots, N\}$:

$$(H_0 + H_f)|\Psi_k\rangle = \lambda_k|\Psi_k\rangle$$

then

$$|\lambda_k - \beta_k| \leq \varepsilon/N$$

and

$$\int_0^{\infty} \left|\varphi^k(x) - \Psi_k(x)\right| \cdot dx \le \varepsilon$$

where φ^k is a Chrestenton function"

Thus computing a discrete function or a discrete process can be approximated by exciting the hardware system appropriately and reading the resulting spectrum.

Computation: The computation, to a large extent, consists in simulating the system characterized by $H_0 + H_f$ using the hardware characterized by H_0, and excited by the field whose Hamiltonian is H_f. Our research about computation is geared towards developing an effective translator that converts an input function or process of the class I into a Hamiltonian operator H and a resolution element that extracts the excitation Hamiltonian H_f. Our long term objectives are to design and implement a prototype system that operates according to the paradigm outlined in this section.

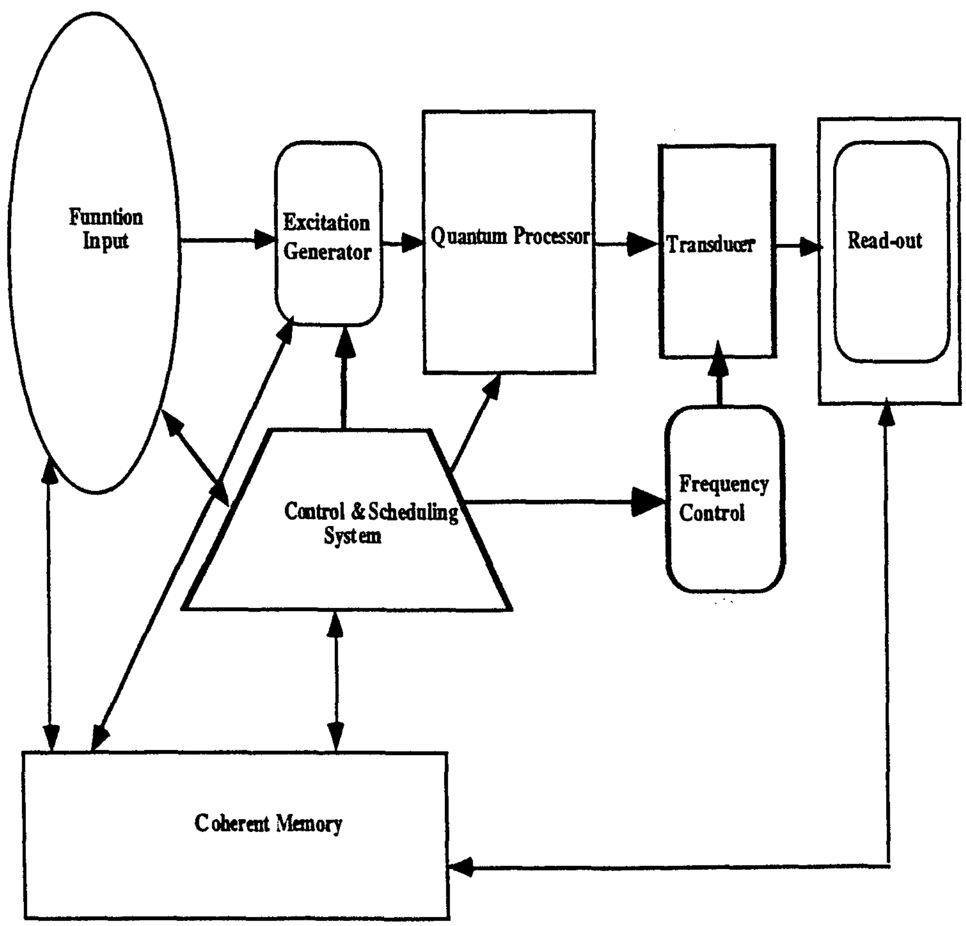

Figure 3. Functional Architecture for Quantum Computing

Architecture

In this section we propose a preliminary design of an architecture that implements the paradigm presented in the previous section. A functional model of our proposed architecture is depicted in Figure 3. We will next discuss briefly the functionality of the elements composing our proposed architecture:

Input Function - Given a discrete function or process to be computed, this element implements the *compilation process;* that is, it determines the excitation Hamiltonian, H_f, which encodes the function or process . This is a symbolic computation whose steps are carried out following the paradigm described in the previous section. These steps can be described by an iterative process such as (3) so in *principle* the compilation process could be carried out by the architecture itself. We will explore the mechanization of the compilation process in this direction.

Excitation Generator - This is a device that realizes *physically* the field excitation encoded in H_f. That is, the excitation generator converts a description of the computation into a physical implementation . The idea is for this device to *address* each individual particle of the quantum process described below and to excite them according to the desired state behavior dictated by:

$$i\hbar\frac{\partial}{\partial t}|\Psi(t)\rangle = (H_0 + H_f)\left(x, \frac{1}{i}\frac{\partial}{\partial x}\right)|\Psi(t)\rangle$$

Our research in this area will be focused on the development of a mechanization process for realizing this functionality. We will consider two alternatives: optical or particle (electron) excitation. A more detailed discussion of these two alternatives will be provided in our next report.

Quantum Processor - This is the device which actually carries the computation. Without excitation, it is a realization of the Hamiltonian H_0. After excitation it is a realization of $H = H_0 + H_f$. We will provide next an abstracted model of the physical characteristics of the Quantum Processor.

The Quantum Processor is an array of identical *particles* assembled into a regular lattice. For the purposes of discussion we will consider a two-dimensional lattice. A later report will be devoted to the formulation of the physical characteristics of the lattice; in this report we will be concerned only with the formulation of some of its computational behavior.

A diagram of the Quantum Processor is shown in Figure 4. The device is composed of two elements: the computational lattice of particles and the field excitation device. From a computational point of view each particle which is allocated to a node in the lattice, can be represented as a non-deterministic, two-level state automaton, and an interface function called Input selector function as shown in Figure 5. We proceed to describe their functionality next.

In the *Lower Automaton*, the block labeled 'State transition' in figure 5 characterizes the programmable discrete spectrum of the particle. The states of the automaton represent energy levels, and edges represent allowable energy transitions. This is illustrated in Figure 6 below.

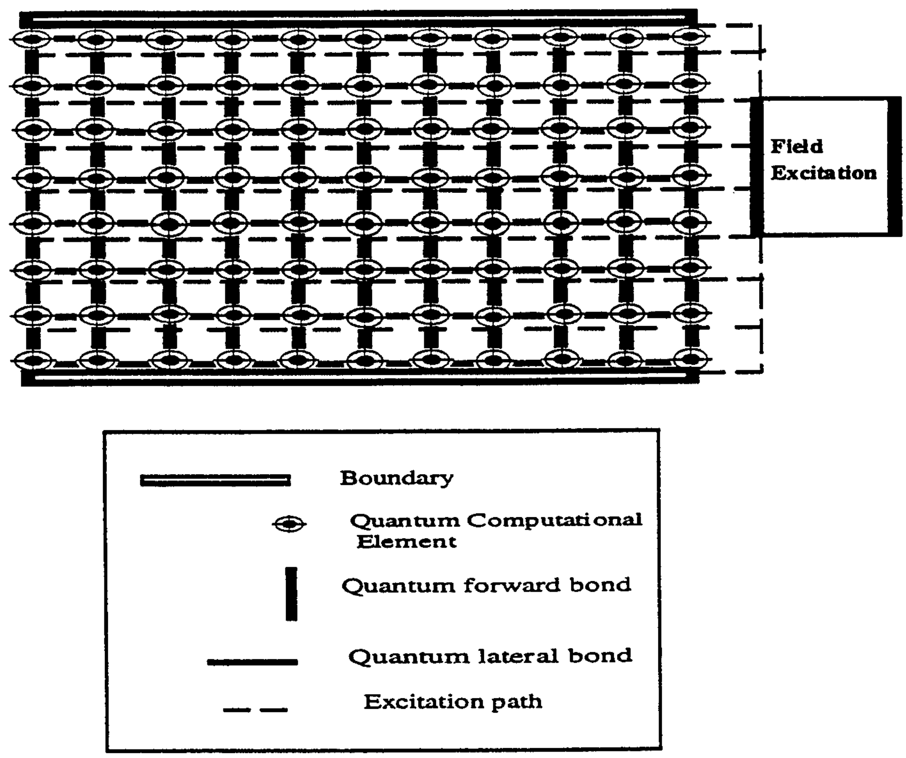

Figure 4. Quantum Processor

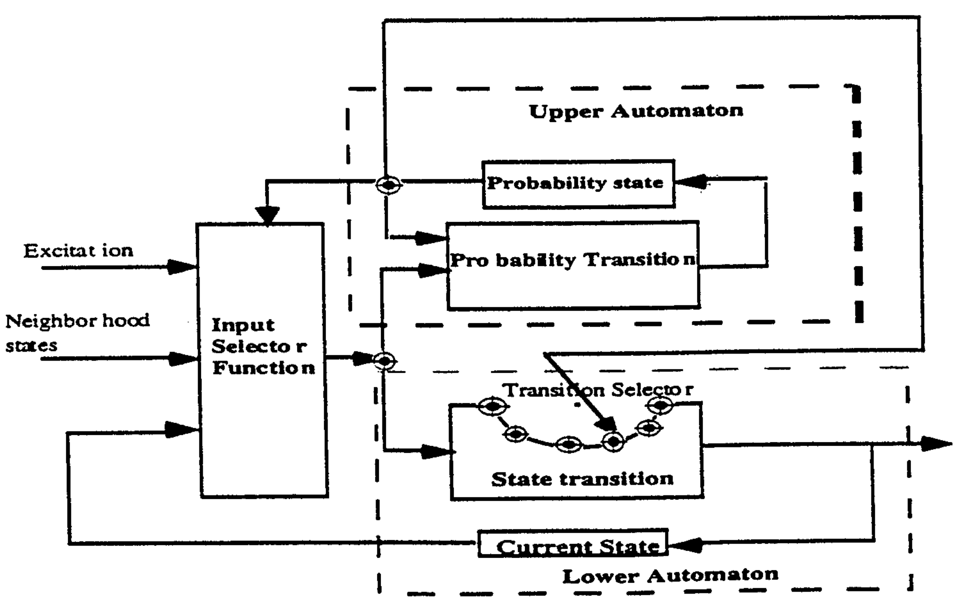

Figure 5. Quantum Particle

In Figure 6, the energy levels correspond to eigenvalues (or sets of eigenvalues forming a band grouped together as a single eigenstate) of the corresponding Hamiltonian. The edges correspond to energy transitions. Edges pointing up are driven by excitation: that is, the transition is effected by absorption of energy from the excitation. Edges pointing down correspond to relaxation effects: the particle releases energy of the appropriate frequency either to neighborhood particles or to the field (see Figure 7).

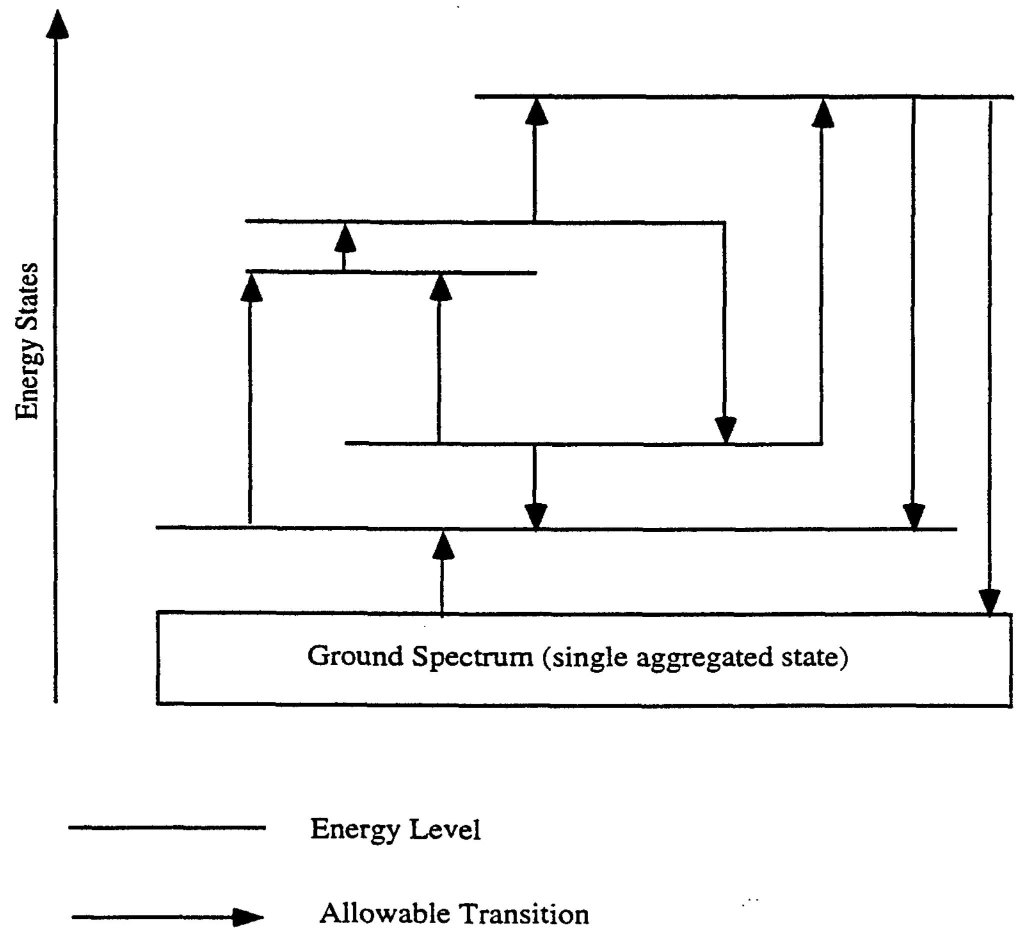

Figure 6. State energy transition example

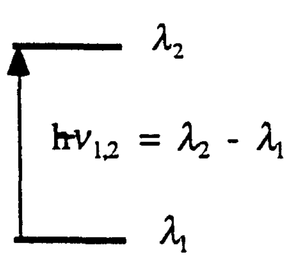

Figure 7. A state transition

In Figure 7, λ_1 and λ_2 are energy levels, and the transition between them is driven by excitation energy to frequency $\nu_{1,2}$. Note from Figure 5 that energy can come to the particle either by interaction with the other particles or from the external excitation. Relaxation transitions are similar.

The state transition in the lower level automaton is controlled by the *mixing state probability density transition* computed by the *Upper Level Automaton*. State transition in this automaton is called 'probability transition' in Figure 5.

The mechanism that implements commands issued by the upper level automaton in the lower level automaton is called *Transition Selector* in Figure 5. We will explain its functionality next. For this we need some preliminary definitions.

Let $S = \{|\Psi_k(t)\rangle,\ k \in N_p,\ N_p \text{ finite}\}$ be the states of the lower automaton in each particle. the let Δ be the *update time* of the particle. The update time of the particle is the determined to be larger than 10 times the maximum relaxation time of any of the state transitions in the lower automaton. The state of the lower level automaton in each interval $[t, t + \Delta)$ is a *Chattering Combination* of the elements of S. A Chattering Combination of the set of functions in the interval is a function $|\Psi(t)\rangle$ defined as follows:

$$|\Psi(\tau)\rangle = \begin{cases} \Psi_{i_1}(\tau) & \tau \in I_{i_1}(t) \\ \Psi_{i_2}(\tau) & \tau \in I_{i_2}(t) \\ \vdots & \\ \Psi_{i_{N-1}}(\tau) & \tau \in I_{i_{N-1}}(t) \\ \Psi_{i_N}(\tau) & \tau \in I_{i_N}(t) \end{cases} \tag{17}$$

where $I_{j_k}(t),\ j_k \in N_p$, is a semi-open interval in $[t, t+\Delta)$:

$$I_{j_k}(t) = \left[t + \sum_{l=0}^{k-1} \Delta_{j_l}(t),\ t + \sum_{l=0}^{k} \Delta_{j_l}(t) \right) \tag{18}$$

We note from (17) that the composite state $|\Psi(\tau)\rangle$ is constructed by 'stitching' together the pure states in S. The time spent in pure state $|\Psi_{j_k}\rangle \in S$, $\Delta_{j_k}(t)$ is a function of the characteristic excitation or relaxation times associated with the state [11]. We note that

$$\sum_k \Delta_{j_k}(t) = \Delta \tag{19}$$

and, if we define

$$\alpha_{j_k}(t) = \frac{\Delta_{j_k}(t)}{\Delta} \tag{20}$$

then equation (19) can be written as

$$\sum_k \alpha_{j_k}(t) = 1 \tag{21}$$

The set of all Chattering Combinations of S in the interval $[t, t + \Delta)$ is denoted by $\hat{S}(t, t+\Delta)$. The union of these sets for all time is denoted by $\hat{S}$. Now we can specify the operation of the Transition Selector in the lower automaton of our particle model. For each interval $[t, t + \Delta)$, the Transition Selector receives a command from the upper level automaton, which consists of an ordered tuple of coefficients $\langle \alpha_{j_k}(t), j_k \in N_p \rangle$ satisfying (21), and then it computes the mixed state of the particle, $|\Psi(t)\rangle$, according to (17). The state of the lattice is composed of the states of each of its particles. We will see shortly that the Chattering Coefficients have the interpretation of state occupancy probabilities. To demonstrate that, we need to discuss the dynamic structure of the upper level automaton.

In general, there is not enough information to say that the lattice or any of its particles is characterized by a specific state function. The best we can do, in order to describe the computation, is to give a probabilistic description. In the quantum formalism, this description is referred to as the probability density description [12].

Let S be the set of primitive states of the lower level automaton. Let p_j be the probability that the particle is in state $\Psi_j \in S$. The probability density operator [13], ρ, is defined by

$$\rho(t) = \sum_j p_j \, |\Psi_j(t)\rangle\langle\Psi_j(t)| \tag{22}$$

By differentiating (22) and using (15), after some algebra, we obtain an (operator) differential equation for ρ :

$$i\hbar \frac{\partial}{\partial t}\rho = H\cdot\rho - \rho\cdot H \tag{23}$$

The operator is termed the commutator and is written as $[H, \rho]$. Thus

$$i\hbar \frac{\partial}{\partial t}\rho = [H, \rho] \tag{24}$$

Given an observable characterized by, say, operator C, the associated observed quantity, denoted by $\langle C\rangle$, is given by the expectation of C relative to ρ :

$$\langle C\rangle = \mathrm{trace}(\rho\cdot C) \tag{25}$$

Equation (24) characterizes the computation carried out by the upper level automaton. Equation (25) characterizes the Transducer of our architecture (see Figure 3). We will devote a future report to discussion of this device in detail.

Notice that the state function, computed by the lower level automaton, could be given as a linear combination of the states in S. We chose to model it as a Chattering Combination, which turns out to be equivalent in a specific sense (as we will show

Notice that the state function, computed by the lower level automaton, could be given as a linear combination of the states in S. We chose to model it as a Chattering Combination, which turns out to be equivalent in a specific sense (as we will show shortly) because in this form it will allow us to formulate the *sequence* of excitation steps (realized by the excitation element, see Figures 4 and 5). To a large extent, programming the quantum processor is tantamount to determining this sequence. To justify this statement, we must explain the sense in which the Chattering and Linear State Combinations are equivalent, because an extension of this result to Excitation Hamiltonians will provide us with a strategy for implementing excitation sequencing .

The equivalence between Linear and Chattering Combinations of state functions from a given set S is established in the following version of the Chattering Lemma [14]:

Chattering Lemma. Let $S = \left\{ |\Psi_k(t)\rangle, \ k \in N_p, \ N_p \text{ finite} \right\}$ and let $\hat{S}$ be the set of chattering combinations of S. Let ε, ε real and positive be given. There exist state functions $|\Theta_j\rangle \in \hat{S}$, defined for each tuple $\left\{ \alpha_1, \ ..., \ \alpha_{n_p} \middle| \alpha_l \geq 0, \ \sum_{l=1}^{n_p} \alpha_l \ = \ 1 \right\}$, such that

$$\max_t \left| \int_0^t \left\{ |\Theta_j(\tau)\rangle - \sum_{l=1}^{n_p} \alpha_l |\Psi_l(\tau)\rangle \right\} \cdot d\tau \right| \ < \ \varepsilon \qquad (26)$$

for all $\left(\alpha_1, \ ..., \ \alpha_{n_p} \right)$.

The proof of this lemma, while not difficult, requires extensive manipulations. We will provide it in a companion report devoted exclusively to the chattering aspects of our proposed architecture. Notice that the lemma says that every chattering combination of state functions of the form of (17) on a set S, can be realized as a linear combination of elements from S with an arbitrary small error in the integral sense (see (26)). We also have the fact that under strong continuity assumptions on the state functions the converse of the lemma is also true. By choosing the boundary conditions in our lattice model appropriately, this assumption is not limiting .

Now we proceed to describe the functionality of the *Input selector function.* This function models the interaction of the particle with the excitation and with the other particles in the lattice. Some examples of possible particle interaction are shown in Figure 8. For simplicity, only nearest neighboring interactions are shown, but the model is not limited to these cases. The central task implemented by the input selector function is to establish on one hand the interaction of a particle with the other particles in the lattice and on the other hand the interaction of a particle with the excitation field in order to characterize these two tasks we look more closely at the excitation field Hamiltonian H_f.

Locally, centered in a particle, it is convenient to write H_f as the sum of two terms, the first, H_e, corresponding to the interaction of the particle with the excitation, and the second H_I corresponding to the interaction of the particle with its internal energy and with the interaction energies of the other particles in the lattice. Thus we write

$$H_f = H_e + H_I \qquad (27)$$

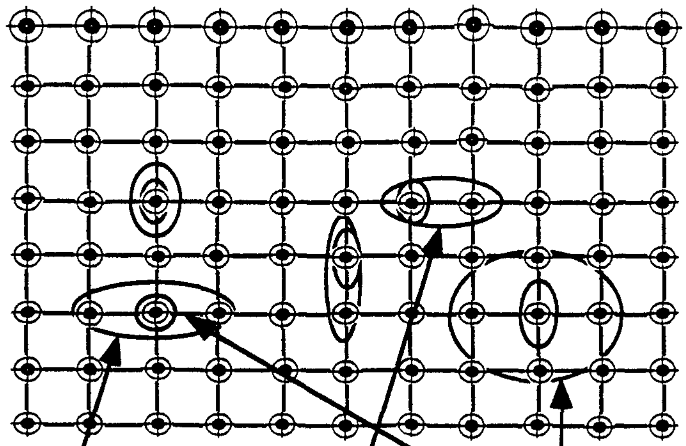

Figure 8. Some examples of particle interaction

Under general assumptions about the lattice, the interaction Hamiltonian H_I for given particle can be written as

$$H_I|\Psi\rangle = g_\Psi\left(H_I^{i_1},\ldots, H_I^{i_k}\right)|\Psi\rangle \tag{28}$$

where $H_I^{i_j}$ for each j is the interaction Hamiltonian of the given particle with its 'neighboring' particle ij , and g_Ψ is the neighborhood function at the current state of the particle, Ψ. The neighborhood function represents the local (at the current state Ψ) structure of interaction of the particles in the lattice. This structure can be determined by building the lagrangian associated with the lattice and go to the procedure of quantization that we discussed earlier. We will carry out this task once the details of the physics of the lattice are defined in the evaluation phase. The approach consist in defining *potentials* to characterize interaction. For example, a dipole (particle-to-particle) interaction between a particle located in coordinates x, y of the lattice may be characterized by a potential V of the form:

$$V(x,y,t) = d_{x-y}(t)\frac{1}{|x-y|}$$

where d_{x-y} is a relaxation function.

For the purposes of analysis and also to determine a detailed formulation of the realization step in our paradigm, it is convenient to assume that a finite set of primitive excitation Hamiltonians $E = \left\{H_e^i ,\ i = 1,\ldots, n_e\right\}$ can be realized and that implementation of our excitation is carried out by *chattering* among the elements of E over the update interval Δ. Specifically,

$$H_e|\Psi(\tau)\rangle = \begin{cases} H_e^{i_1}|\Psi(\tau)\rangle & \tau \in I_{i_1}(t) \\ H_e^{i_2}|\Psi(\tau)\rangle & \tau \in I_{i_2}(t) \\ \vdots & \\ H_e^{i_{n-1}}|\Psi(\tau)\rangle & \tau \in I_{i_{n-1}}(t) \\ H_e^{i_n}|\Psi(\tau)\rangle & \tau \in I_{i_n}(t) \end{cases} \tag{29}$$

Where the sets $I_{i_j}(t)$ are defined by expression (18). This type of *probabilistic resonance* is central to our proposed implementation of the quantum processor. The idea is to induce a probability distribution ρ on the states of the particles on the lattice so that the realization criterion is satisfied.

Thus a computation in the lattice is a propagating probabilistic wave-train in which the state of each particle is the probability distribution of its pure states. This is illustrated in Figure 9. Specifically the lattice is at an initial probabilistic state, the programmed excitation is impinged and after a transient period ξ has elapsed, the read out period, the transducer is activated to effect the eigen-value observation. After the observation has been made, the computation process is complete. If the results are not satisfactory the computation is started again from the initial probabilistic state and the read-out period is extended to $\xi_1 > \xi$. This extension period cannot be extended arbitrarily because the thermal relaxation mechanisms in the lattice will induce eventually *decoherence*, that is, the loss of the probabilistic resonance described above.

Let $\{E_i\}$ be the discrete spectrum of the physical Hamiltonian H_0. Then it can be shown using (24), that the transition probability ρ_{ij} from eigenstate i to eigenstate j satisfies,

$$i\hbar\frac{\partial}{\partial t}\rho_{ij}(t) = \left(E_i - E_j\right)\cdot\,\rho_{ij} + \left[H_f, \rho\right]_{ij} \tag{30}$$

In [11], it is shown that if the system is at state $|\Psi_j\rangle$ at time t= 0, then the presence of the relaxation Hamiltonian (28) causes the corresponding probability density term ρ_{jj} *to decay exponentially with time.* For small values of t, ρ_{jj} is the largest term in the matrix representation of the probability density operator. Assuming no excitation, and using (30) this term satisfies the following equation:

$$i\hbar\frac{\partial}{\partial t}\rho_{jj} = \sum_k\left((H_1)_{jk}\rho_{kj} - \rho_{jk}(H_1)_{kj}\right) \tag{31}$$

with

$$i\hbar\frac{\partial}{\partial t}\rho_{ji} \cong \left(E_j - E_i\right)\cdot\,\rho_{ji} - \rho_{jj}\cdot(H_1)_{ji} \quad \text{for } i \neq j \tag{32}$$

The solution of (31) and (32) for ρ_{jj} is given by:

$$\rho_{jj}(t) = e^{-t/\xi} \tag{33}$$

where ξ is a relaxation time that depends on the physical characteristics of the lattice. Thus the effect of the inter particle excitation Hamiltonian is to randomize the state transitions in each particle. The computation described above will be corrupted by this effect. Therefore, the read-out period ζ must be chosen so that this effect is acceptable; this means $\zeta << \xi$. We will use this bound in our design specifications of the quantum processor and also, in our computability analysis.

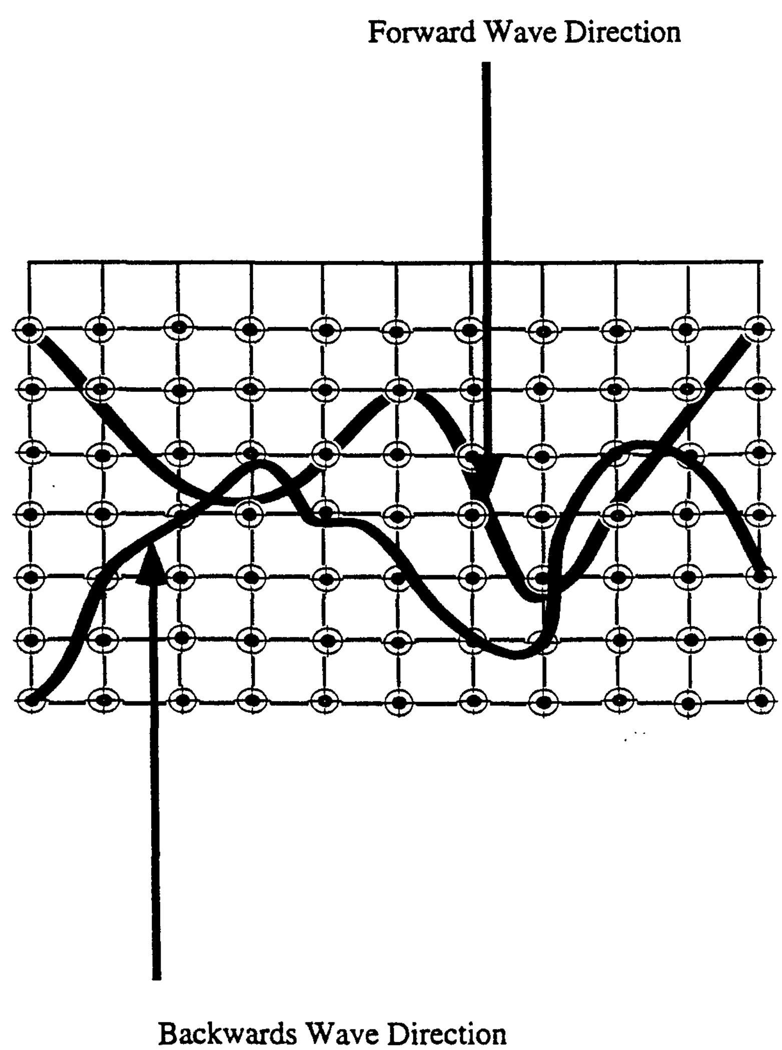

Figure 9. Wave Propagation

Conclusions

In this paper we present a preliminary design of a hardware architecture for computing initial segments of primitive recursive functions and iterative processes. The formulation of the architecture is based in a paradigm which proposes a procedure for 1- encoding a function or process and 2- Carry out the computation. The paradigm is firmly rooted in the formalism of quantum mechanics. We propose as our representation of the architecture a generic regular multiparticle, two-dimensional lattice. This lattice is a model of crystal structures that in principle, can be produced in the lab today.

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A Center for Excellence in Mathematical Sciences

Final Progress Report

by

Anil Nerode

February 18, 1997

U.S. Army Research Office
DAAL03-91-C-0027

Cornell University

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FOREWORD

This contract was a continuation of earlier contracts for the Army Center of Excellence in Mathematical Sciences established in January 1986. The Mathematical Sciences Institute provided a center of focus of the continuation of development of mathematics in the traditional areas, and more importantly, the extension of research into new areas with the development of new directions for mathematics.

The philosophy behind a center for mathematical research is that only a center has the capacity to meet cross-disciplinary challenges which must combine talents of computer scientist, mathematicians, scientists, and engineers. A center can be used to create a positive national climate for the development of an entire subject by providing a forum of interaction to create a national community of researchers. A center with flexible funding and insightful leadership can identify and nurture emerging research areas which have high risk of failure but high potential of return. The Mathematical Sciences Institute has provided this leadership and flexibility to meet the changes in mathematical science as technology and knowledge expands.

The proposal maintained the Mathematical Sciences Institute as the overall center for administration and program direction, with the responsibility to oversee three smaller Centers of Excellence in the Mathematical Sciences for: Nonlinear Analysis, Stochastic Analysis, and Symbolic Methods in Algorithmic Mathematics. Each of these centers pursued advancements in their areas but also coordinated and collaborated between centers. This model was extremely successful. And, as funding levels changed it was possible to allocate available resources to those programs exhibiting the greatest potential. During the over ten years of operations, the Mathematical Sciences Institute proved the value of such centers and gained an international reputation as "the" center for mathematical excellence.

FINAL REPORT (4a & 4b)

Since this contract provided funding for three centers which each addressed a number of different areas of research, rather than just one distinct line of study, this report will provide information on the problems studied and results obtained by each Center of Excellence.

Center of Excellence in the Mathematical Sciences for Nonlinear Analysis

Statement of the Problems Studied:

Nonlinear analysis is the fundamental mathematical theory describing complex and nonlinear systems and nonlinear materials. With a new, and correct, mathematical basis for understanding the interactions of nonlinear waves, the science of nonlinear and complex materials will proceed more rapidly. Similarly, the study of phase portraits for dynamical systems and the classification of trajectories by their asymptotic or chaotic behavior yields invaluable insight into system behavior, while the study of bifurcation's of dynamical systems and the development of computation methods brings mathematics to bear on the complex problems of modern science and engineering.

Mathematical theory alone is not sufficient for today's science. A close interplay between mathematical theory and advanced computational algorithms is necessary. Novel and powerful algorithms and computational methods, especially tailored to the mathematical features of problem difficulties, will be developed.

Pursue the subjects of mathematical analysis, numerical analysis, development of advanced computational methods, modeling of physical phenomena and technology transfer. Work on four aspects of nonlinear analysis: nonlinear waves, dynamical systems, nonlinear materials and high resolution flow simulation. Stability, bifurcation and transition to chaos are part of the dynamical systems effort. Modeling of nonlinear material strength included theories of ductile and brittle failure, leading to plastic and granular flow. The computational methods focus on high resolution schemes and on the use of parallel computer architecture's.

Summary of the Most Important Results:

James Glimm, with P. Colella and G. Pucket, showed the dependence of wave structure on wave impedance. J. Grove and L. Coulter have developed a general package within the area of piece wise continuous interpolation. B. Plohr and D. Sharp succeeded in casting the equations governing the elasto-plastic behavior of real materials in a fully conservative form in the Eulerian frame.

Y. Deng, J. Glimm, Q. Yu, and Y. Wang motivated by structural problems in binding of protein on DNA, an optimization problem was solved. The objective function (binding free energy) to be minimized has a very large number of local minima, and the problem is to find a search algorithm which will find all of these with energy close to global minimum. The problem was solved efficiently, using (a) combinatorial methods (b) matrix theory and (c) Monte Carlo search. The later method alone would have been very inefficient.

J. Grove, with Y. Deng and G. Li< developed a robust version of the front tracker method suitable on any distributed memory parallel computer. This method uses a geometric domain decomposition algorithm and has been shown to be up to 90% efficient in utilization of parallel processors.

J. Grove, with F. Wang, B. Plohr, and D.H. Sharp, developed a numerical method for the computation in Eulerian coordinates of elasto-plastic flows of materials. This method combines a conservative Eulerian formulation of the equations of motion with higher order Godunov methods and front tracking.

B. Plohr discovered a new and fully conservative formulation of plasticity. Such a conservative form is necessary for treating discontinuous solutions, such as arise in Riemann problems. Based on the importance of the conservation formulation for other computations, we expect the conservative formulation of plasticity to be fundamental. A model of shear bands has been developed which solves in part the problem of jump conditions across a shear band, following earlier results of Wright and Walter. Jump conditions are needed to allow front tracking for shear bands.

J. Bramble, X. Zhang, and J. Pasciak have developed a general theory for constructing preconditioners. The show how to precondition one system by means of a related (simpler) one. The theory is applied to many different elements useful for biharmonic problems.

Center of Excellence in the Mathematical Sciences or Stochastic Analysis

<u>Statement of the Problems Studied:</u>

Apply the ideas of probability theory to a wide variety of fields: biology (ecology, genetics), chemistry, physics (statistical mechanics, field theory, quantum mechanics), economics, finance, computer and communication networks, and to mathematics itself (partial differential equations, harmonic analysis, and differential geometry). Three specific areas of research are conducted:

- Interactions with Partial Differential Equations -- Relationships between interacting particle systems and measure valued diffusions with nonlinear p.d.e.'s.

- Applications to Physics and to Mathematics -- two programs on (a) problems in probability arising from mathematical physics and (b) applications of probability to topics in analysis and geometry.
- Poisson and Brownian Models -- theory and applications of processes driven by Brownian motion and Poisson processes. Topics included the theory of stochastic differential equations and their applications to finance and queuing theory; external and stable processes as alternatives to Gaussian models; random sets in economics, inference, and image analysis.

Summary of the Most Important Results:

R. Durrett culminated work, with C. Neuhauser, on particle systems and reaction diffusion equations. M. Cranston completed work on probabilistic approach to Martin boundaries on manifolds with ends. H. Kesten obtained a bound for speed of convergence to the time constant in the first-passage percolation. C. Mueller showed that blow-up can occur for the heat equation with a certain nonlinear noise term and showed long-time existence for the wave equation in one and two dimensions. J.T. Cox and A. Greven completed work on an analysis of the basic ergodic theory of a class of interacting diffusions.

The relationship between particle systems and nonlinear partial differential equations was used in work by G. Swindle showing coexistence results for catalysts. These models of the oxidation of carbon monoxide on catalyst surfaces have been around for a number of years, but now we have the first results for a model that shows all three phases: poisoning to al oxygen, poisoning to all carbon monoxide, and the physically desirable case of coexistence of the two species, which allows the reaction to occur at a positive rate.

A class of processes known as super processes have been investigated by many authors. A new insight into the structure of a branching, measure-valued processes was obtained in a joint work of E.B. Dynkin and A.V. Skorokhod. Tools have been developed which allow construction explicitly of all such processes.

C. Mueller proved regularity properties for three dimensional wave equations with nonlinear noise terms.

L. Billera and B. Sturmfels completed their work on iterated fiber polytopes, establishing a connection between subdivisions and allowable sequences.

Center of Excellence in the Mathematical Sciences for Symbolic Methods in Algorithmic Mathematics

Statement of the Problems Studied:

The Center emphasizes development of mathematics and algorithms for the manipulation, simplification, and solution of problems that represent the mathematical structures symbolically, no matter what branch of mathematics or science the problem come from, coupled with applications areas in business, government, and military. Initial areas of concentration are a Groebner Basis Project and a Symbolic Methods in AI and Computer Science project, with simultaneous development of other needed areas. The research plan consists of work in three specific areas:

- The Computational Algebra and Mathematics Program -- pursue optimization of the primary Groebner construction algorithm. Develop an algebraic theory of piece wise polynomial approximation based on the Bezier-Bernstein algebra. Address questions surrounding polytopes, splines, and complexity of Groebner basis computations. In topology determine the homotopy type of subdivision lattice of a polytope. Research automating perturbation calculations for dynamical systems.
- Mathematics of AI and Concurrency Program -- model AI, computer science, and physical and engineering science problems in logical systems, and solve such problems using mathematical logic methods from semantics, syntactics, model theory, automated deduction. Model (non-statistical) inference based on incomplete but correct information, to develop algorithms and automated deduction engines for this purpose, and to use models and software in specific applications.
- Unification of Symbolic Methods -- emphasize unification of algebraic and logical methods in symbolic computation. Develop an understanding of the symbolic-numeric interface, and a base for adding numerical analysis features to the model. Develop a new model of Hybrid systems, using the variety of talents in logic, algebra, combinatorics, dynamical systems, and numerical analysis.

Summary of the Most Important Results:

A. Nerode, with P. Broome and J. Lipton, established a mathematical underpinning for relational programming and with V.S. Subrahmanian, C. Bell, and R. Eng, developed a compiler for implementing deductive database theory by linear programming. M. Kalkbrener, with B. Sturmfels, proved that the simplical complex defined by any initial ideal of prime is pure and strongly connected.

R. Rand, with S. Lubkin, developed mathematical models for the "circumnutation" phenomenon observed in certain species of plants. These growth movements involve a circular motion of the stem with a period of about 2 hours. The mathematical model involves reaction diffusion equations in the cross-section of the stem. The research tries to explain observations of biologists relating to the effect of environmental changes on amplitude and period of oscillation.

L. Tuncel solved very large (up to 13 million variables) linear programming problems while studying the asymptotic behavior of interior point algorithms for linear programs. Further study proved that when n is infinite one can still get a complexity bound on the number of iterations required in terms of smoothness of the problem and the desired accuracy.

H. Blair, with W.V. Marek and J. Schlipf, established that all hyperarithmetic sets of atomic formulas are definable as projections onto particular predicates within the unique stable models of locally stratified logic programs. The result is a concrete representation theorem that identified a natural subclass of the class of logic programs with unique stable models previously identified by Marek, Nerode, and Remmel. H. Blair and M. Bai, developed a non-intuitionistic intensional model theory for higher-order Horn logic programs based on the extended simply typed lambda calculus in a manner that extends the notion of Herand models.

A. Nerode designed a game model for distributed computing based on message passing in OCCAM). The defect in previous universal theories was that the Rabin theory has a doubly exponential lower bound, and universally regarded as unfeasible. However, we believed that for problems that occur in practice, this unfeasibility is absent. Yakhnis and Yakhnis in 1990, found a substantially better decision method for this calculus, but their account was murky and still too complicated to apply in practice. A student of Gurevich put their proof into clear form. Using this as a starting point R. McNaughton found a graph formulation of the extraction of winning strategies for games. This has been improved by Remmel, Nerode, and Yakhnis to the point that we can now solve small games by hand and extract the winning strategies.

J. Underwood defined a new model theory for classical logic which highlights its connection to intuitionistic logic. This model theory hints at a connection with parallel computation. There appear to be deep connections with linear logic in the proof theory as well.

N. Vorobjov constructed several new effective algorithms for basic computational problems in real algebraic and analytic geometry. An algorithm for finding all irreducible components of the Zariski-closure of a semialgebraic set obtain, with A. Galligo, was extended to transcendental varieties defined by polynomial in exponent equations. The running time of both algorithms is single-exponential in number of variables.

A. Nerode and W. Kohn developed practical software tools to extract digital control automata for distributed autonomous systems using a combination of algorithms from relaxed variational problems, Hamilton-Jacobi-Bellman systems, dynamic programming, finite dimensional Lie Algebras associated with physical systems, relaxed variational calculus for compact convex problems, and algorithms from Eilenberg for solving implicit equations in Schutsennberger series for finite automata.

A. Barvinok has shown in the counting of lattice points, that the computation of a fixed number of the highest coefficients of the Ehrhart polynomial of a convex integral polytope reduces the polynomial time to the computation of the volume of faces. This result implies, in particular, that counting integral points in a polytope of a fixed dimension can be performed in polynomial time. Although the latter result (which settled and open problem) was obtained earlier by the author, the new methods gives the best complexity so far.

D. Bridges and C. Calude produced what appears to be the first rigorous proof of a folklore result about the non-existence of recursive bounds for the exceptional values in Blum's Speed-up Theorem.

S. Marcus with V.S. Subrahmanian proved that the problem of updating (monotonic) deductive databases (both insertions and deletions) has simple, elegant analogs in nonmonotonic reasoning formalisms including both default and auto-epistemic logic. Subsequently, they showed that the problem of updating nonmontonic deductive databases can also be viewed in terms of such analogs. Thus, nonmonotonic reasoning provide a general declarative framework whereby a wide variety of database updating problems may be clearly specified.

A. Nerode and W. Kohn developed a physically feasible scheme for quantum computing. It is based on a new computing paradigm, which encodes programs, including mixed digital and continuous directly in shaped Schrodinger equation. This is implemented by an array of quantum devices, in the eigenvalues of associated operators. The problem is solved by exciting with emitter apparatus physical array to initial conditions, and is run for what is the equivalent of 1.5 trillion operations, stopped before decoherence makes the results unreadable by spectrographic methods. There are no non-physically realizable steps in either the reading in or the reading out processes.

M. Sweedler and L. Taylor developed a technique for computing Groebner bases for zero dimensional ideals which are the kernals of maps to algebras or modules where one can compute linear independence. Unlike previous techniques this method does not require an initial set of generators for the ideal.

M. Stillman with D. Grayson, has implemented the software system Macaulay-2. More than 60000 lines of code have been written, and much of it is extremely succinct. Stillman has been mainly responsible for the polynomial and matrix arithmetic, the faster Groebner basis, resolution, Hilbert function and related algorithms, and Grayson has been mainly responsible for the presentation of high-level mathematical concepts and interpreted language.

K. Shirayanagi and M. Sweedler developed the theory and technology for automatic stabilization of a wide class of algebraic algorithms which are not inherently stable. For example, the usual form of the Euclidean algorithm for polynomials with rational or real coefficients is not stable. These techniques also permit the use of floating point and other inexact computation in order to stabily approximate a large class of non-inherently stable algorithms. The techniques also enables the development of a computer algebra system which, like Maple or Mathematica, allows the expression of algorithms, but unlike other systems also allows the user to tell the system to stabilize the algorithm.

<u>List of Publications and Technical Reports (4c)</u>

MSI TECHNICAL REPORTS June 1991 - December 1996

91-57	Estimating The Critical Values of Stochastic Growth Models L. Buttel, J.T. Cox and R. Durrett 9 pages
91-58	A Note on Polynomial Reductions Alyson Reeves and Bernd Sturmfels 5 Pages
91-59	On The Asymptotic Distribution of Large Prime Factors Peter Donnelly and Geoffrey Grimmett 12 Pages
91-60	Maximal Minors and Their Leading Terms Bernd Sturmfels and Andrei Zelevinsky 42 Pages
91-61	On The Rate of Convergence of the Nonlinear Galerkin Methods Christohe Devulder, Martine Marion and Edriss S. Titi 36 Pages
91-62	Theory Tabeaux Ian Gent 16 Pages
91-63	A Context For Belief Revision: Normal Logic Programs W. Marke, A. Nerode and J. Remmel 6 Pages

91-64	The Evolution of The Anisotropy Of A Polycrystalline Aggregate Ying Zhang and James T. Jenkins 42 Pages
91-65	Multigraded Resultants of Sylvester Type Bernd Sturmfels and Andrei Zelevinsky 1 Pages
91-66	Computing Circumscriptive Deductive Databases Anil Nerode, Raymond T. Ng and V.S. Subrahmanian 11 Pages
91-67	Computation and Implementation of Non-Monotonic Deductive Databases Colin Bell, Anil Nerode and V.S. Subrahmanian 55 Pages
91-68	The Lexicographic Order Isn't Necessarily The Worst Alyson A. Reeves 5 Pages
91-69	Competitive Coexistence In A Seasonally Fluctuating Environment Toshiyuki Namba 30 Pages
91-70	On Branching Numbers of Normal Manifolds Daniel Ralph 16 Pages
92-1	Particle Systems and Reaction-Diffusion Equations Richard Durrett and C. Neuhauser 45 Pages
92-2	Computing Circumscriptive Databases, Part I: Theory and Algortihms Anil Nerode, Raymond T. Ng and V.S. Subrahmanian

92-3	A Fast Algorithm For Path Integration Dov Bai 4 Pages
92-4	Product Formulas For Sparce Resultants Paul Pedersen and Bernd Sturmfels 22 Pages
92-5	Approximating Oracle Machines For Combinatorial Optimization Shmuel Onn 4 Pages
92-6	Dynamical Simulation Faculity For Hybrid Systems Allen Back, John Guckenheimer, and Mark Myers 12 Pages
92-7	Multigrid Preconditioning For The Biharmonic Direichlet Problem M.R. Hanisch 33 Pages
92-8	The Expressiveness of Locally Stratified Programs Howard A. Blair, Wiktor Marek, and John Schlipf 27 Pages
92-9	Nontrivial Dynamics In A Driven String With Impact Nonlinearity Theo P. Valkering 34 Pages
92-10	A Note On The Primal-Dual Affine Scaling Algorithms Levent Tuncel 11 Pages
91-11	On The Convergence of Primal-Dual Interior Point Methods With Wide Neighborhoods Levant Tuncel 26 Pages

91-12 Primitive Polynomial Remainder Sequences In Elimination Theory
Michael Kalkbrener
16 Pages

91-13 Generalized Euclidean Algorithm For Computing Triangular Representation Of Algebraic Varities
Michael Kalkbrener
30 Pages

92-14 Initial Complexes Of Prime Ideals
Michael Kalkbrener and Bernd Sturmfels
10 Pages

92-15 A Generalized Euclidean Algorithm for Geometry Theorem Proving
Michael Kalkbrener
25 Pages

92-16 Asymptotic Behavior of Excitable Cellular Automata
Richard Durrett and David Griffeath
39 Pages

92-17 Fixed-Parameter Tractability And Completeness II: On Completeness For W[1]
Rod Downey and Michael Fellows
14 Pages

92-18 Fixed-Parameter Intractability II (Extended Abstract)
Rod Downey and Michael Fellows
10 pages

92-19 Fixed-Parameter Tractability and Completeness III: Some Structural Aspects of the W Hierarchy
Rod Downey and Michael Fellows
24 Pages

92-20 A Practical Feasible Square Packing Algorithm For Chip Manufacture In VLSI (In Honor of Anil Nerode's Sixieth Birthday)
Wenqui Huang and Moss Sweedler
17 Pages

92-21 The Stable Models Of A Predicate Logic Program[1]
V. Wiktor Marek, Anil Nerode and Jeffrey Remmel
29 Pages

92-22 Exact Formulas For The Plethysms $S_2[S(1^a,b)]$ And $S_{1^2}[a(1^a,b)]$
J.O. Carbonara, J.B. Remmel and M. Yang
16 Pages

92-23 A Classical Type Theory With Tranfinite Types
Garrel Pottinger
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92-24 Computation of Vector Space T^1 For Affine Toric Varieties
Klaus Altmann
23 Pages

92-25 Gurevich-Harrington's Games Defined By Finite Automata
Alexander Yakhnis and Vladimir Yakhnis
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92-26 Models For Hybrid Systems: Automata, Topologies, Stability
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95-22	Hybrid Systems As Finsler Manifolds: Finite State Control As Approximation To Connections Wolf Kohn, Anil Nerode, And Jeffrey B. Remmel 28 Pages
95-23	On Complements Of Subanalytic Sets And Existential Formulas For Analytic Functions Andrei Gabrielov 18 Pages
95-24	Geometric Incompatibility In A Fault System Andrei Gabrielov, Vladimir Keilis-Borok, And David D. Jackson 40 Pages
95-25	McNaughton Games And Extracting Strategies For Concurrent Programs (Revised) Anil Nerode, Jeffrey B. Remmel, And Alexander Yakhnis 54 Pages

95-26	What's Decidable About Hybrid Automata Thomas A. Henzinger, Peter W. Kopke, Anuj Puri, And Pravin Varaiya 47 Pages
95-27	Recursive Models Of Theories With Few Models Bakhadyr Khoussainov, Andre Nies, And Richard A. Shore 18 Pages
95-28	A Theory Of Stabilizing Algebraic Algorithms Kiyoshi Shirayanagi And Moss Sweedler 92 Pages
95-29	Operational Modal Logic Sergei N. Artemov 29 Pages
96-1	There Is No Degree Invarient Half-Jump Rod Downey And Richard Shore 7 Pages
96-2	Splitting Theorems And The Jump Operator Rod Downey And Richard Shore 11 Pages
96-3	Intervals Without Critical Triples Peter Cholak, Rod Downey And Richard Shore 30 Pages
96-4	Computably Categorical Structures And Expansions By Constants Peter Cholak, Sergey Goncharov, Bakhadyr Khoussainov And Richard Shore 36 Pages
96-5	Self Equivalences For Rectangular Hybrid Auomata Thomas A. Henzinger and Peter W. Kopke 22 Pages
96-6	Proof Realization of Intuitionistic and Modal Logics S. Artemov

96-7	Categoricity and Scott Families Bakhadyr Knoussainov, Richard Shore 12 Pages
96-8	Decidable Kripke Models of Intuitionistic Theories Hajimee Ishihara, Bakhadyr Khoussainov, Anil Nerode 11 Pages
96-9	Topological Semantics For Intuitionistic Logic and Hybrid Systems (Preliminary Report) Sergei Artemov, Jennifer Davoren, Anil Nerode 9 pages
96-10	Tableaux for Functional Dependencies and Independencies Duminda Wijesekera, M. Ganesh, Jaideep Srivastava, and Anil Nerode 15 pages
96-11	Distributed Multiple-Agent Command and Control for Theatres of War: Reactive Control of Distributed Interactive Simulations (DIS): Wolf Kohn, John James and Anil Nerode 30 pages

List of Participating Scientific Personnel(4d)

Center of Excellence in the Mathematical Sciences for Symbolic Methods in Algorithmic Mathematics

Visitors

J. Lipton - U. Penn. 5/3/91-8/1/91- Visiting Scientist
A. Yakhnis -9/20/90-6/30/95, Visiting Scientist
V. Yakhnis - 5/10/94-6/23/94 - Visiting Scientist, IBM
Dov Bai - Postdoc/Visiting Fellow,8/1/89-5/16/94 Utah State Univ.
Rodney Downey - Victoria University, New Zealand,8/6/92-12/23/92, Visiting Scholar
Howard Blair - School of CA and Info. Sci., Syracuse U. ,Visiting Fellow 11/15/91-11/14/94
B. Khoussaniov - 7/1/93-6/30/95 - Visiting Scientist, Tash Kent Univ.
Garrel Pottinger - 9/1/92-8/31/95 - Visiting Fellow, Odyssey Research
Sherry Marcus- 6/3/93-10/15/93 - Visiting Scientist, Harvard Univ.
Jeff Remmel-UCSD-Visit. Sci. 6/15/93-9/15/93 and 8/10/92-9/3/92
Alan Paris - 12/8/94-2/7/95 and 5/20/94-8/18/94
David Harel 10/1/94-5/15/95, Visit. Scientist
D. Nies - 1/5-5/24/95, Visit.Sci.
Alexei Myasnikov- 3/3/93-3/12/93 - Univ. of Manitoba, Visit. Sci.
S. Artemov - Visit. Sci. 6/30/93-7/31/93 - Steklov Math. Inst.
David Morrison- Duke University, 1/5/95-5/24/95
Sergey Goncharov, Visit. Sci. 10/25/94-11/25/94 - Inst. of Math, Douglas
D. Bridges - Univ. of Waikato 7/1/93-8/4/93
E. Ardeleanu - Non-degree Student Fall 93 and Spring'94 LINZ Austria, RISC-Johannes Kepler Univ.
Xiaolin Ge - 8/11/93-8/10/95 Univ. of Minnesota
Allen Brown - Visiting Fellow 5/12/92-5/11/94 - Xerox Corp.
Mikhail Taitslin - Visit. Fellow 5/30/93-6/30/93 - Tver Univ. Russia
M. Kalkbrenner - RISC, LINZ, Austria - Visiting Scientist
O. Moreno - Puerto Rico
Stavros Busenberg, Math Harvey Mudd
Beat Jaggi - Switzerland, Univ. Berne 8/23/92-8/23/93
Kiyoshi Shirayanagi - NTT Comm. Sci. Lab, Japan, Visiting Scholar 8/92-7/93
Nicolai Vorobjov - Steklov Inst., Russia 8/1/92-6/30/93, Visiting Scientist
Hajime Ishihara - Japan Advanced Inst. of Science & Tech - 2/1/93-12/1/93
Wolfgang Vogel - University of Halle, 5/13-5/26/93, Visit. Sci.

Alexandre Barvinok - Dept. of Math, Royal Inst. of Tech., Sweden 8/1/93-8/1/94
Douglas Bridges University of Waikato, New Zealand, 7/1/93-1/31/94
Andrei Gabrielov - 8/1/94-7/31/95 Universityof Toronto
Nobuki Takayama - Dept. of Math Kobe Univ., Japan - 7/12/93-3/30/94
John Little - College of the Holy Cross, Worcester, MA (Math) 8/19/93-7/31/94
Clara Chan - (Billera) - Virginia Polytech Inst. 9/13/94-12/31/94
Sorin Popescu - 3/1/94-3/24/94 - Univ. of Saarland, Germany
Titi, Edriss S., 8/1/91-8/31/91
Allen Back - Research Associate 5/11/91-7/1/93
Warren Nichols - Visiting Fellow

Cornell Faculty
Anil Nerode - Mathematics
Moss Sweedler - Mathematics
Richard Shore- Mathematics
Richard Zipple - Computer Science
Keith Dennis - Math
Chris Heegard -Elec. Engr.
Paul Chew - Computer Science
Al Schatz - Mathematics
Kenneth Brown - Mathematics
Dexter Kozen - Computer Science
Louis Billera - Mathematics
R. Rand - T&AM
Michael Stillman - Math
Bernd Sturmfels - Math
Bruce Donald - Comp. Sci.
Mark Gross - Math

GRA/Fellowships

Amy Briggs - CS - GRA - Summer 92
David Chang - CS GRA - Summer 92
Suresh Chari - CS- GRA - Summer 92
Niandong Liu - Math -GRA - Summer 92
Shmuel Onn - ORIE - GRA AY 91-92
KeithSaints - Appl., Math AASERT Fellow - ARO Summer Fellow 93
Aravind Srinivasan - CS - GRA - Summer 92
Levent Tuncel - ORIE - GRA - AY 91-92
Judith Underwood - CS - GRA - Summer 93, Summer 92, A& 91/92, 92/93
Ivelisse Rubio - Fellowship 91/92, 92/93,93/94,94/95
F. Bohringer - CS - Summer 93
Pankaj Rohatgi - CS - Summer 92
Rekha Thomas - ORIE - GRA Summer 93
Kjartan Stefansson - Summer 94
Sarangarajan - Summer 91
Subramanya, Rao - Summer 95, Elec. Engr., GRA
Oliva 92/93 Fellow, Math
Robert Milnikel, Spr. '94 Fellow - Math
Peter Rapkin - SUmmer 91 - GRA
Worfolk, Sum 91 - GRA

Levant Tuncel - AY 91-92 - GRA
Mitchell - 93/94 GRA and summer 94
P. Pedersen, Computer Science
Zhang - Summer 91 - GRA
Sindhushayana - Summer 92 - GRA
Peter Kopke - Computer Science
Henry Schenck - Math
A. Santos - Fall 96
S. Carver - Fall 95 - Applied Math
S. Mason - Fall 96 - Applied Math

Visitors

J.T. Cox - Dept. of Math, Syracuse Univ. 6/8/92-8/7/92 and 6/1/93-6/30/93
M. Cranston - Dept. of Math, University of Rochester
E.B. Dynkin - Dept. of Math, Cornell
H. Kesten - Dept. of Math, Cornell
Carl Mueller - Dept. of Math, University of Rochester, 8/4/92-9/4/92
S. Levin - Ecology, Cornell
J. Gravner - Postdoc 9/1/91-5/31/92, Univ. of Wisconsin, Madison
Toshiyuki Namba - Senshu University, Japan 5/31/91-3/12/92
Steven Kalikow -Visting Scientist, 7/1/91-7/1/93 - Univ. of Southern Calif.
Kenneth Hochberg - Visiting Scientist, 8/6/92-11/25/92 - Case Western Reserve
Roland Dobrushin - 1/93-6/30/93 - Visit. Sci. Inst. for Problems of Infor. Transmission, Russia
Norio Konno- Visiting Scholar - 5/1/93-2/28/94, Muroran Inst. of Tech, Japan
Wenzhang Huang (Chavez) Visit. Sci. Pomona College 2/17/94-8/17/94
Joseph Yukich- Visiting Fellow, Lehigh University 9/8/94-1/1/95
Jorge Velasco-Hernandez - 8/15/94-2/1/95 - UAm Iztapalapa, Visit. Sci.
Robert Fisch - 12/6/93-12/5/94, Visit. Sci. Univ. of Wisconsin, Madison
Andreas Greven- Visit. Sci. 8/24/91-10/15/91, Univ. of Gottingen
Michail Menchikov- Visit. Sci. 7/25/91-9/15/91 - Moscow Univ.
Serge Kuznetsov 5/15/94-5/27/94 - Visit. Sci., Central Econ. - Math Inst. of Russian Academy of Sciences
Tomasz Zaks,- Visit. Sci. 3/15/92-4/15/93 - Tech. Univ. of Wroclaw
Kai-Lai Chung 7/1/94-8/1/94 - Visit. Sci., Stanford University
RimasNorvicha - 4/27/92-5/26/92, Visit. Sci. Inst.of Math at Vilnius, Lithuania
Jia Li - 5/13/93-9/16/93 - Visit. Sci. Univ. of Alabama
Suetlozar Rachev - 6/18/93-7/17/93 - Visit. Sci. U.C. Santa Barbara
David S. Griffeath University of Wisconsin, 7/22/93-8/22/93
Braverman, (Samorodnitsky, OR) Russia 10/1/93-12/1/93

GRA

Hassan Allouba - Applied Math, GRA - Sum 93, Sum. 94
Susan Lee - Math GRA, Summer and Spring 93
H. Dengler - Math - GRA Spr. 93
Friedman - Summer
Brige - GRA Sum 93, Sum. 94, Appl. Math
Bobrovnikova GRA Sum. 93 - Appl. Math
Kunzelman GRA Spr. 94- Appl. Math
Schwab - non-degree Spr. 94

Postdocs
Itai Benjamini - Postdoc -8/1/93-5/24/95- Hebrew Univ.
Kathleen Crowe - Postdoc - 7/21/92-7/26/94 - Went to Humboldt State University
Peter Antal 8/15/94-2/28/95 - Swiss Federal Inst. of Tech, Postdoc
Jeff Steif - Postdoc, 7/1/91-8/31/91 - Rutgers Univ.
D. McBeth, Douglas, Postdoc 8/22/91-12/25/91 - Hewlett Packard and ORIE (Cornell)

Cornell
Richard Durrett - Math
Carlos Castillto-Chavez - Plant Breeding, Cornell
L. Buttel - Plant Breeding
E. Dynkin - Math
H. Kesten - Math
L. Billera - Math

Center of Excellence in the Mathematical Sciences for Nonlinear Analysis

Visitors

J.E. Pasciak - SUNY Stony Brook - Visiting Scientist 6/25/94-7/25/94
Paulauskas, Vygantas 12/124/93-5/11/94- Visit. Sci., Vilnius Univ., Lithuania
Vidar Thomee, Visit. Sci. 6/20/91-8/20/91 - Sweden

Postdocs
Z. Leyk - Postdoc 8/1/89-7/31/91 - Univ. of Warsaw
Zuejun Zhang - Postdoc 8/16/93- 8/17/95 - Univ. Maryland, D.Y.M.
Hanisch - Postdoc 8/91-5/13/93 (Cornell)

GRA/FELLOWS
Yaoping Zhang - GRA AY 83/94 and 94/95
Dunlap - Fellow 92/93, 93/94, 94/95
Baggett - Fellow Jall 93, Spr. 94

Cornell Faculty

James Bramble - Math

Advanced Degrees Earned

Ph.D. Degrees Awarded

- Hassan Allouba - [redacted] - CAM - Ph.D. 8/96
- Susan Lee - [redacted] - Math - Ph.D. 8/22/94
- Yuan-Chung Sheu - [redacted] - Math - Ph.D. 8/23/93
- Heike Dengler - [redacted] - Math - Ph.D. 1/19/94
- Erich Friedman - [redacted] - Ph.D. 5/26/91
- Amy Briggs - [redacted] - Comp. Sci., - Ph.D. 1/18/95
- Suresh Chari - [redacted] - Comp. Sci. - Ph.D. 8/22/94
- Niandong Liu - [redacted] - Math - Ph.D. 5/28/95
- Shmuel Onn 5/92 - ORIE - Ph.D. 8/24/92
- Keith Saints - [redacted] - CAM - Ph.D. 1/18/95
- Aravind Srinivasan - [redacted] - Comp. Sci. - Ph.D. 8/23/93
- Levent Tuncel - [redacted] - ORIE - Ph.D. 1/20/93
- Judith Underwood - [redacted] - Comp. Sci. - Ph.D. 8/22/94
- Pankaj Rohatgi - [redacted] - Comp. Sci. - Ph D. 1/19/94
- Rekha Thomas - [redacted] - Math - Ph.D. 8/22/94
- Kjartan Stefansson - [redacted] - Comp. Sci. - Ph.D. 5/28/95
- Riccardo Oliva - [redacted] - Math - Ph.D. Expected 5/97
- Peter Worfolk - [redacted] - Ph.D. 8/23/93
- N. Sindhushayana, - [redacted] - EE- Ph.D. 1/18/95
- Richard Dunlap - [redacted] - Math - Ph.D. 8/96
- Jeffrey Baggett - [redacted] - Math - Ph.D. 8/96
- Don Allers - [redacted] - CAM - Ph.D. Expected 8/97
- Bruce Anderson - [redacted] - Ph.D. 5/24/92
- Sunchual Lee - [redacted] - Math - Ph.D. 5/29/94
- Henry K. Schenck - [redacted] - CAM - Ph.D. Expected 8/97
- Jennifer Davoren - [redacted] - Math - Ph.D. Expected 8/97

REPORT OF INVENTIONS: None

BIBLIOGRAPHY: See list of Publications and Technical Reports (4c)

APPENDIX A

MSI Workshops and Seminars June 1991-December 1996

Workshops and Seminars June 1, 1991-December 31, 1991

Hybrid Systems Workshop, June 10-12, 1991

Patch Dynamics in Terrestrial, Marine, and Freshwater Ecosystems, June 23-July 19, 1991

Combinatorics and Discrete Geometry Workshop, July 17-20, 1991

First International Workshop on Logic Programming and Non-Monotonic Reasoning, July 22-24, 1991

Modern Computational Methods in Industrial Mathematics, August 15-16, 1991

Computational Geometry Workshop, October 25-26, 1991

Nonlinear Analysis Conference, November 21-23, 1991

Seminars

Mikhail Kapranov, MSI and Northwestern University, Chow Quotients of Gassmann Varieties, MSI Seminar on Combinatorial and Algebraic Geometry, June 3, 1991

S. A. Molchanov, Moscow University, Intermittancy in Random, Nonstationary Median, Probability Seminar, September 2, 1991

Wolfgang Vogel, University of Halle, Algorithms in Intersection Theory, Combinatorial and Algebraic Geometry Seminar, September 9, 1991

Andreas Greven, MSI and University of Gottingen, The Speed of a One-dimensional, Self-repellent Random Walk, Probability Seminar, Sept. 9, 1991

Wolfgang Vogel, Univ. of Halle, A Converse to Bezout's Theorem, MSI Lecture, Sept. 10, 1991

Paul Pedersen, Cornell University, Solving Systems of Algebraic Equations, Center for Applied Mathematical Colloquium, Sept. 13, 1991

Sundaram Thangavelu, Cornell Univesity, Multiple Laguerre Expansions, Analysis Seminar, Sept. 16, 1991

Michael Kalkbrenner, MSI, An Algorithm for Solving Systems of Algebraic Equations, Combinatorial and Algebraic Geometry Seminar, Spt. 16, 1991

Larry Gray, Univ. of Minnesota, Gac's Counterexample to the Positive Rate Conjecture, Probability Seminar, Sept. 16, 1991

Anil Nerode, MSI and Cornell University, 1991 MSi Fall Colloquium, Sept. 17. 1991

Anil Nerode, MSI and Cornell University, How to Use Linear Programming to do Logic, I, Logic Seminar, Sept. 19, 1991

Richard Durrett, MSI and Cornell University, A New Game for Your Computers, Olivetti Club Seminar, Sept. 19, 1991

John Guckenheimer, Cornell University, Computing Dynamical Systems Computer Science Seminar, Sept. 19, 1991

David Eisenbud, Brandeis Univ., Computational Problems Coming from Algebraic Geometry, Combinatorial and Algebraic Geometry Seminar, Sept. 23, 1991

Moss Sweedler, MSI and Cornell University, An Overview of Symbolic Computation at Cornell, Bill Sears Club Seminar, Sept. 24, 1991

Arjen Doelman, University of Utrecht, Quasi-periodic and Homoclinic Solutions of Degenerate Modulation Equations, Dynamics Seminar, Sept. 25, 1991

Michael Kalkbrenner, MSI, CASA: A Computer Algebra Package for Constructive Algebraic Geometry, Olivetti Club Seminar, Sept. 26, 1991

Bernd Sturmfels, Cornell University, What Is the Determinant of a Rectangular Matrix?, Combinatorial and Algebraic Geometry Seminar, Sept. 30, 1991

Geoffrey Grimmett, Bristol University, Random Walk on the Infinite Cluster of the Percolation Model, Probability Seminar, Sept. 30, 1991

John Hubbard, Cornell University, Complex Analysis and Dynamical Systems, Bill Sears Club Seminar, Oct. 1, 1991

Anil Nerode, MSI and Cornell University, How to use Linear Programming to do Logic, II, Logic Seminar, Oct. 3, 1991

Steven Diaz, Syracuse University, Families of Branched Covers of the Sphere, Combinatorial and Algebraic Geometry Seminar, Oct. 7, 1991

D. Rubin, Cornell University, Non-linear Dynamics in a Electron Storage Ring, Theoretical and Applied Mechanics Colloquium, Oct. 16, 1991

Dan Edidin, Syracuse University, An Introduction to the Moduli Space of Curves, Combinatorial and Algebraic Geometry Seminar, Oct. 21, 1991

Lawrence Payne, Cornell University, On the Eigenvalues and Eigenfunctions of the Lpalacian, Olivetti Club Seminar, Oct. 24, 1991

Michael Stillman, Cornell University, A Geometric Method for Computing Syzygies, I, Combinatorial and Algebraic Geometry Seminar, Oct. 28, 1991

Michael Stillman, Cornell Univesity, A Geometric Method for Computing Syzygies, II, Combinatorial and Algebraic Geometry Seminar, Nov. 4, 1991

Anil Nerode, MSI and Cornell University, Game Semantics for a Fragment of Linear Logic, Logic Seminar, Nov. 5, 1991

Moss Sweedler, MSI and Cornell University, Symbolic Computation, MSI Symbolic Lunch, Nov. 7, 1991

John Hubbard, Cornell University, Superattractive Fixed Points of Mappings in CN, Analysis Seminar, Nov. 11, 1991

Marshall Cohen, Cornell University, Lickorish's Construction of Non-shellable Spheres, Combinatorial and Algebraic Geometry Seminar, Nov. 11, 1991

James Lipton, MSI and Univ. of Pennsylvania, Semantic Methods for Type Theory and Term Extraction, Logic Seminar, Nov. 12, 1991

David Cox, Amherst college, Algebraic Cycles and Simply-connected Elliptic Surfaces, Combinatorial and Agebraic Geometry Seminar, Nov. 18, 1991

Richard Shore, Cornell University, Post's Program -Guaranteeing Incompleteness, Logic Seminar, Nov. 19, 1991

Davdatt Dubbhashi, Cornell University, Thom's Lemma and Applications, MSI Symbolic Lunch, Nov. 20, 1991

Louis Billera, Cornell University, Structure for Splines and Triangulations, Bill Sears Club Seminar, Nov. 26, 1991

Richard Shore, Cornell University, Post's Program, II, Logic Seminar, Nov. 26, 1991

J.T. Jenkins, Cornell University, Instabilities in Rapid Granular Flows, Stability, Transition, and Turbulence Seminar, Dec. 3, 1991

Bruce Donald, Cornell University, Computing the Homology Type of at Triangulation, Center for Applied Mathematics Colloquium, Dec. 6, 1991

Workshops and Seminars January 1, 1992-June 30, 1992

January 5-8, 1992
MSI Director Anil Nerode organized a workshp on Autonomous Control Systems in conjunction with the Second International Symposium on Artificial Intelligence and Mathematics which met in Ft Lauderdale, Florida

April 19-21, 1992
S.R.S. Varadhan of the Courant Institute organized a workshop on Hydrodynamic Limits which met at MSI in Ithaca, New York

May 1, 1992
Edward Beltrami of SUNY Stony Brook organized the Fourth Annual Conference on Biomathematics which met at the MSI/Stony Brook Center for the Mathematics of Nonlinear Systesms.

May 10-12, 1992
Dr. Griffeath of the University of Wisconsin, Madison organized a workshop on Cellular Automata which met at MSI in Ithaca, New York.

May 28-30, 1992
Jeffrey Remmel of UCSD and Peter Clote of Boston College organized a workshop on Feasible Mathematics II which met at MSI in Ithaca, New York.

June 1-3, 1992
Richard Shore and Moss Sweedler of Cornell, Jeffrey Remmel of UCSD, and John Crossley of Monash University organized a conference on Logical Methods in Mathematics and Computer Science which met at Cornell University in Ithaca, New York.

June 22-July 17, 1992
The Mathematical Sciences Institute and the Cornell Center for Applied Mathematics were cosponsores of the extended workshop Patch Dynamics II which met at the Engineering and Theory Center, Cornell University in Ithaca, New York.

Seminars

Michael Kalkbrener, MSI and Cornell University, MSI seminar on Combinatorial and Algebraic Geometry, February 10, 1992

Janko Gravner, MSI and Cornell University, MSI seminar on Annihilating Nested Rings, March 2, 1992

Bernd Sturmfels, MSI and Cornell Univesity, MSI seminar on How to Divide a 12-gon into Parallelograms, March 5, 1992

Jeremy Titelbaum, University of Illinois, Chicago, MSI seminar on Some Algorithms, March 9, 1992.

Klaus Altmann, Berlin, MSI seminar on Combinatorial and Algebraic Geometry, Toric Methods in Singularity Theory, March 23, 1992

Paul Pedersen, MSI and Cornell University Seminar on Probability, Oriented Percolation in High Dimension, March 30, 1992

Tomasz Zak, Wroclaw Tech. Institute, Cornell University Operations Research Colloquium, Anderson Inequality is Strict for Gaussian and Stable Measures, March 31, 1992.

Steven Kalikow, MSI, Cornell University Seminar on Probability, Uniform Martingales and Random Markov Chains, April 13, 1992.

Anil Nerode, MSI and Cornell University, Cornell Seminar on Logic, Logic and Hybrid Systems, April 14, 1992.

Levant Tuncel, MSI and Cornell University, Cornell Seminar on Operations Research, Asymptotic Behavior of Interior Point Methods, April 14, 1992.

Michael Stillman, MSI and Cornell University, Cornell Seminar on Computing, Algebraic Geometry, April 21, 1992

Richard Durrett, MSI and Cornell University, Cornell Seminar on Coexistence Results for Catlysis, April 27, 1992.

H. Kesten, MSI and Cornell University, Seminar on Greedy Lattice Animals, June 10, 1992.

Workshops and Seminars July 1, 1992 - December 31, 1992

M. Stillman and B. Sturmfels of Cornell were organizers for the Regional Institute in Geometry and Computational Algebraic Geometry which met at Amhurst College, Amherst, Massachusetts, June 22-July 17, 1992

C. Mueller of the University of Rochester organized a workshop on Stochastic Partial Differential Equations which met at the University of Rochester, July 17-18, 1992

J. Chiment of MSI organized a program on the Mathematics of Everyday Things for elementary and high school teachers which met at the Mathematical Sciences Institute, Ithaca, New York, July 20-24, 1992

A. Nerode, MSI Director, was program chair for the symposium on Logical Foundations of Computer Science which met at Tver University, Russia, July 20-24, 1992

M. Sweedler, ACSyAM Director, was an organizer for the International Symposium on Symbolic and Algebraic Computation which met in Berkeley, California, July 27-29, 1992

M. Sweedler, ACSyAM Director, and P. Pedersen of Cornell University hosted a workshop on Real Algebra which met at the Mathematical Sciences Institute in Ithaca, New York, August 24-26, 1992

S. Busenberg of Harvey Mudd College organized the Industrial Mathematics Workshop on Semiconductor Simulation which met at the Claremont College, Claremont, California, August 28-29, 1992

M. Cranston of the University of Rochester and MSI Center Director Richard Durrett organized a workshop on Stochastic Analysis which met at the Mathematical Sciences Institute in Ithaca, New York, September 13-15, 1992

E. Tardos of Cornell University, in conjunction with the U.S.-Hungarian Science and Technology board, organized a workshop on Combinatorial Optimization which met at the Mathematical Sciences Institute, Ithaca, New York, October 5-9, 1992

R. Connelly of Cornell University organized a workshop on Higher Level Rigidity which met at the Mathematical Sciences Institute, Ithaca, New York, Ocotber 11, 1992

A. Scedrov of the University of Pennsylvania and MSI Director A. Nerode organized Jumelage 92 which met at the Mathematical Sciences Insitute, Ithaca, New York, October 15-17, 1992

MSI Director A. Nerode, in conjunction with H. Blair of Syracuse University and A. Brown, Jr. of the Xerox Webster Research Center, organized a workshop on Documents, Computation, and Preference which met in Washington, D.C., October 21-23, 1992

J. Mitchell and S. Skiena of SUNY Stony Brook organized a conference on Computational Geometry which met at MSI/Stony Brook, October 23-24, 1992

MSI Director A. Nerode Chaired the Joint International Conference and Symposium on Logic Programming which met in Washington, D.C., November 9-12, 1992

W. Marek of the University of Kentucky and MSI Director A. Nerode organized the Workshop on Structural Complexity and Logic Programming which met in Washington, D.C., November 13, 1992

D. Ferguson of SUNY Stony Brook helped to organized a workshop on Applied Mathematics: Prospect for the 1990's which met at Suffolk Community College, November 13-14, 1992

J. Maceli of Ithaca College, in conjunction with ACSyAM Director M. Sweedler and MSI Center Director R. Durrett, organized a workshop on MSI-related research at the regional meeting of the Mathematical Association of America which met at Cornell University, Ithaca, New York, November 14, 1992

MSI Director A. Nerode organized a special session on Hybrid Systems at the IEEE Conference on Decision and Control which met in Tucson, Arizona, December 16-18, 1992

Seminars

J. Steif, Chalmers University of Technology, Gottenberg, Sweden, MSI Summer Seminar in Probability on Non-uniqueness of Measures of Maximal Entropy, July 1, 1992

R. Schinazi, University of Colorado, MSI Summer Seminar in Probability on Multple Phase Transitions for Branching Markov Chains, July 7, 1992.

J. Quastel, University of California, Davis, MSI Summer Seminar in Probability on Introduction to the Entropy Method or Hydrodynamic Limits, July 8, 1992.

R. Durrett, MSI and Cornell, MSI Summer Seminar in Probability on Interacting Particle System Models of Ecosystem Dynamics, July 14, 1992.

J. Chiment, MSI, Cornell Institute for Biology Teachers Lecture on The Statistical Analysis of Fossils, July 16, 1992

J. Gravner, MSI, MSI Summer Seminar in Probability on Metastability in Greenberg Hastings Dynamics, July 21, 1992

J. Remmel, UCSD, Cornell Logic Seminar on McNaughton Games, September 1, 1992.

R. Connelly, Cornell, MSI Combinatorial and Algebraic Geometry Seminar on Counter-examples to Definitions of Higher-order Rigidity, September 7, 1992.

E. Dynkin, Cornell, Cornell Probability Seminar on Branching, September 7, 1992.

R. Downey, MSI and Victoria Univ., Cornell Logic Seminar on Effective Presentations of Linear Orderings and Boolean Algebras, September 10, 1992

O. Harlen, Cambridge, Center for Applied Mathematics Colloquium on Fiber Suspensions, September 11, 1992.

B. Jaggi, MSI and Univ. Bern, MSI Combinatorial and Algebraic Geometry Seminar on Configuration Spaces of Planar Polygons, September 14, 1992

R. Downey , MSI and Victoria Univ., Cornell Logic Seminar on Effective Presentations of Linear Orderings and Boolean Algebras II, September 17, 1992.

P. Pedersen, Cornell, MSI Symbolic Discussion Group lecture on Macaulays 1903 Paper on Resultants, September 21, 1992.

W. Vogel, MSI Combinatorial and Algebraic Geometry Seminar on the Castelnuovo-Mumford Regularity, September 21, 1992.

R. Durrett, MSI and Cornell, Cornell Probability Seminar on Asymptotic Critical Value for a Competition Model, September 21, 1992.

P. Pedersen, Cornell, MSI Symbolic Discussion Group lecture on Macaulay's 1903 Paper on Resultants III, September 28, 1992.

R. Pemantle, Univ. of Wisconsin, Cornell Oliver Club Seminar on Probability on Trees, October 6, 1992.

G. Domokos, Tech. Univ. Budapest, Cornell Dynamics Seminar on Global Description of Equilibrium Paths in Elastic Bars and Strings, October 7, 1992.

G. Domokos, Tech. Univ. Budapest, Cornell Theoretical and Applied Mechanics Seminar on Nonlinear Computational Methods for Structures with Discreet Rotational Symmetry, October 7, 1992.

A. Nerode, MSI and Cornell, Cornell Logic Seminar on A Hybrid Systems Model, October 8, 1992.

J. Chiment, MSI, Corning Community College Mathematics Field Day lecture on the Mathematics of Telling a Lie, October 10, 1992

L. de Haan, Univ. of Rotterdam, Cornell Statistics Seminar on Statistical Problems of Multidimensional Extremes, October 14, 1992.

R. Shore, Cornell and Cornell Logic Seminar on Low 2 R.E. Sets, October 22, 1992.

L. de Haan, Univ. of Rotterdam, Cornell Probability Seminar on the Tail Empirical Process and Extended Regular Variation of Second Order, October 26, 1992.

K. Saints, Cornell, MSI Symbolic Discussion Group Lecture on Error Correcting Codes, October 26, 12992.

T. Coleman, Cornell, Cornell Computational Optimization Seminar on The Reflective Newton Method for Large-scale Nonlinear Minimization with Simple Bound Constraints, October 26, 1992.

P. Worfolk, Cornell Cornell Dynamics Seminar on Instant Chaos, October 28, 1992.

L. Harkleroad, Cornell Olivetti Club lecture on Solitare Card Games--From Graph Theory to Combinatorial Group Theory, October 29, 1992

C. Goldie, Queen Mary College, Cornell Probability Seminar on Differences Between Record Values and Order Statistics Revisisted, November 2, 1992.

B. Goldfarb, Cornell, Cornell Olivetti Club lecture on Geometrically Controlled Algebra, November 5, 1992.

A. Lutoborski, Syracuse University, Cornell Center for Applied Mathematics Colloquium on Mean Coercive Functionals in Calculus of Variations, November 6, 1992.

K. Shirayanagi, MSI and NTT, MSI Combnatorial and Algebraic Geometry Seminar on Using Grobner Bases to Decide Whether Finite-dimensional Noncommutative Algebras are Isomorphic, November 9, 1992.

K. Fleischman, Univ. of Berlin, Cornell Probability Seminar on Diffusive Clustering for Hierarchially Interacting Diffusions, November 9, 1992.

K. Saint, Cornell, MSI Symbolic Discussion Group Lecture on A Decoding Algorithm which Locatoes Errors by Means of Groebner Bases, November 11, 1992

B. Khoussainov, MSI and Tashkent Univ., Cornell Logic Seminar on Recursive Unary Algebras, November 12, 1992

S. Mizuno, Inst. Stat. Math., Cornell Center for Applied Mathematics Colloquium on Polynomiality of Infeasible-interior point Algorithms, November 13, 1992.

L. Billera, Cornell, MSI Combinatorial and Algebraic Geometry Seminar on Iterated Fiber Polytopes, November 16, 1992.

K. Hochberg, MSI and Bar-Ilan Univ., Cornell Probability Seminar onMulti-level Branching Diffusions and Super Processes, November 17, 1992.

B. Driver, UCSD, Cornell Oliver Club Seminar on What Happens When You Blow on Perfume Diffusing in A Manifold?, November 23, 1992.

M. Sweedler, MSI and Cornell, MSI Symbolic Discussion Group lecture on Multivariate Sturms Theorem, November 23, 1992.

J. Bramble, MSI and Cornell, Cornell Advanced Computing Research Institute lecture on Multigrid as a Preconditioner for Elliptic Problems, November 30, 1992.

M. Sweedler, MSI and Cornell, MSI Symbolic Discussion Group lecture on Multivariate Sturms Theorem II, November 30, 1992.

G. Berkooz, Cornell, Cornell Stability, Transition, and Turbulence Seminar on What Do Simulations Reproduce Statistics?, December 1, 1992.

R. Rand, Cornell, Cornell Center for Applied Mathematics Seminar on Dynamics of Separatrix Crossing and Resonant Capture, Decembe 2, 1992.

H. Blair, Syracuse Univ., Cornell Logic Seminar on Some Complexity Results for Logic Programming Semantics, December 3, 1992.

S. Adian, Steklov Institute, MSI Symbolic Discussion Group lecture on Some Worked Problems for Groups and Semigroups, December 7, 1992.

Workshops and Seminars January 1, 1993-June 30, 1993

O. Moreno of MSI/University of Puerto Rico organized the Workshop in Codes and Exponential Sums over Finite Fields which met at the Rio Piedras campus of the University of Puerto Rico under Army Research Office sponsorship, January 25-29, 1993.

A. Nerode of MSI/Cornell organized a Workshop on Hybrid Systems and Autonomous Control which met at the Mathematical Sciences Institute in Ithaca, New York, February 16-19, 1993

E. Beltrami organized the Fifth Annual Conference on Biomathematics which met on the SUNY Stony Brook campus of the State University of New York. The conference was hosted by MSI/Stony Brook, April 16, 1993.

R. Pemantle of the University of Wisconsin organized the Workshop on Random Walks, Trees, and Groups which met at the Mathematical Sciences Institute in Ithaca, New York, April 18-20, 1993.

O. Moreno of MSI/University of Puerto Rico, T. Mora of Genova, and G. Cohen of Paris organized the Tenth International Symposium on Applied Algebra, Algebraic Algorithms, and Error Correcting Codes which met in San Juan de Puerto Rico, May 10-14, 1993.

A. Scedrov of the University of Pennsylvania organized the Workshop on Linear Logic which met on the campus of Cornell University, June 14-18, 1993.

The Mathematical Sciences Institute in conjunction with Cornell's Center for Applied Mathematics, the Woods Hole Oceanographic Institution, the National Science Foundation, and the Office of Naval Research, sponsored a summer course on Structured Population Models in Marine, Terrestrial, and Freshwater Systems. The course met at Cornell University, June 16-July 16, 1993.

D. Heath and S. Resnick of Cornell University organized a Workshop on Applied Probability in honor of N.U. Prabhu which met at the Mathematical Sciences Institute in Ithaca, New York, June 28-29, 1993

MSI Director A. Nerode organized a meeting at the Second International Workshop on Logic Programming and Nonmonotonic Reasoning with met in Lisbon, Portugal, June 28-30, 1993.

Workshops and Seminars July 1, 1993 - December 31, 1993

R. Durrett, Director of MSI Center for Stochastic Analysis, co-chaired the American Mathematical Society's 41st Summer Research Institute, which met at Cornell University, June 16-July 16, 1993

Peter Paule from the University of Linz organized a workshop on Symbolic Computation in Combinatorics, which met at the Mathematical Sciences Institute in Ithaca, New York, September 21-24, 1993

Bernd Sturmfels of MSI/Cornell organized a joint U.S.-Italian conference on Hilbert Function, which met at the Mathematical Sciences Institute in Ithaca, New York, October 27-30, 1993

Anil Nerode, Director of MSI, sponsored the Second Workshop on Sturctural Complexity and Recursion -theoretic Methods in Logic Programming that was hel in conjunction with the 1993 Symposium on Logic Programming in Vancouver, British Columbia, Canada, October 27-29, 1993.

Jim Bramble of MSI/Cornell organized the Finite Element Circus, which met in Snee Hall on the Cornell campus, November 12-13, 1993

Seminars

Alexander Barvinok, MSI and St. Petersburg," Counting integral points in Polynomial time". August 1993

Eugene Dynkin, Cornell Univesity, "Branching with a single point catalyst", September 6, 1993

Nobuki Takayama, MSI and Kobe University, "Secondary polytopes and hypergeometric D-modules", September 6, 1993

John Little, MSI and Mount Holycross, "The Petri Scheme", September 6, 1993

Nobuki Takayama, MSI and Kobe University, "Introduction to algebraic analysis by the computer algebra system "kan", September 13, 1993

Susan Lee, Cornell University, “Optimal drift for diffusions on [0,1]”, September 3, 1993.

Richard Zippel, Cornell University, “Functional decomposition and platonic solids” September 12, 1993

Paul Pedersen, “About the European PosSO Project and possible cooperation”, September 16, 1993.

Mark Gross, Cornell University, “Calabi-Yau threefolds: A survey and some results”, September 20, 1993.

Heike Dengler, Cornell University, “Poisson approximations to continuous security market models”, September 20, 1993

Peter Cholak, Cornell University visitor, “Post’s program and the lattice or recursively enumerable sets”, September 23, 1993

Ted Cox, MSI, Syracuse University,” Finite and infinite systems of interacting diffusions”, September 27, 1993.

Laura Anderson, MSI and MIT, “ Combinatorial differential manifolds”, September 27, 1993.

Dexter Kozen, “The Complexity of Set Constraints”, September 30, 1993.

Paul Pedersen, Cornell University, “Mixed monomial bases”, October 4, 1993.

Norio Konno, Cornell University visitor, “Asymptotic behavior of basic contact process with rapid stirring”, October 4, 1993.

Mike Stillman, Cornell faculty ”Macaulay: the next generation”, October 7, 1993.

Jeffrey Remmel, MSI and UCSD, “Speedable and levelable sets and vector spaces”, October 14, 1993

Paul Edelman, Cornell Univesity, Plane partitions, free arrangements, and fiber zonotopes”, October 18, 1993.

David Heath, Cornell University, “Martingales, arbitrage and completeness”, October 18, 1993.

Douglas Bridges, MSI visitor, “Varieties of constructive mathematics”, October 21, 1993.

Paddy Farrell, Cornell visitor, “Lower Complexity Soft-Decision Decoding for Block Code”, October 21, 1993.

David Morrison, Cornell visitor from Duke University, “Mirror symmetry and toric geometry”, October 25, 1993.

Michael Braverman, Cornell visitor from Russian Acad. of Sciences,” Characterizations of probability distributions by moment conditions”, October 25, 1993.

Boris Kushner, Cornell visitor from Univ. of Pittsburgh, “On the definition of computable functions over reals”, October 28, 1993.

Alexander Barvinok, Cornell visitor from St. Petersburg, “Topology and Convex Geometry of Quadratic Equations”, November 1, 1993.

Marat Arslanov, Cornell visitor from Kazan Univ., “Completeness in the arithmetical hierarchy and fixed points”, November 4, 1993.

Claudia Neuhauser, Cornell visitor from Univ. of Wisconsin-Madison, “Coexistence for a catalytic surface reaction model”, November 6, 1993.

Martin Guest, Cornell visitor from Rochester, “The space of rational curves on a toric variety”, November 8, 1993

Marat Arslanov, Cornell visitor from Kazan Univ., “Completeness in the arithmetical hierarchy and fixed points”, November 9, 1993.

Jacob E. Goodman, Cornell visitor from CUNY, “Convexity on Affine Grassmann Manifords”, November 9, 1993.

John Little, Cornell visitor from Holycross College, “Algebraic Coding Theory”, November 11, 1993.

Melvin Fitting, Cornell visitor form CUNY, “Logic programming and metric methods”, November 18, 1993.

Elman Izadi, Cornell visitor from Harvard Univesity," The intermediate Jacobians of the theta divisors of four-dimensional polarized abelian varieties", November 19, 1993.

John Little, MSI and Holycross College, "The Hilbert Scheme of Genus 6 Canonical Curves", November 22, 1993.

S. Aida, Cornell visitor from University of MIT, "Exponential integrability derived from Poincare and logarithmic Sobolev Inequalities", November 22, 1993.

John Little, Cornell visitor from Holycross College, "The Petri Scheme Revisited", November 29, 1993.

Michael F. Singer, "Testing reducibility of linear differential equations", December 2, 1993.

Workshops and Seminars January 1, 1994-June30, 1994

Lend Adleman from the University of Southern California and Moss Sweedler from Cornell University were the organizers for ACSyam's ANTS-1, the first Algebra and Number Theory Symposium, held at MSI, May 6-9, 1994.

R. Getoor from UCSD and H. Kesten from Cornell University organized a workshop, "In Honor of E. Dynkin" held at MSI, May 22-24, 1994.

Joseph Mitchell from SUNY Stony Brook organized the "Tenth Symposium on Computational Geometry", June 6-8, 1994.

The State Univeristy of New York at Stony Brook hosted the Fifth International Conference on Hyperbolic Problems. June 13-17, 1994.

Xiaolin Ge, MSI, "Computability in Banach spaces", February 3, 1994.

Sheldon Katz, Oklahoma State University, "Polar duality and mirror symmetry for hypersurfaces in weighted projective space", February 7, 1994.

Z. Chen, University of Californiaat San Diego "Reflecting Brownian motions and their applications to Sobolev spaces", February 7, 1994.

A. Myasnikov, McGill University, "Computability over the reals and the p-adic numbers: Are they the same?", February 10, 1994.

Peter March, Ohio State Univesity, "Moment equations of probability measure-valued processes", February 14, 1994.

Bakhadyr Khoussainov, MSI, "Games, monadic theories and automata", February 15, 1994.

Takis Souganidis, University of Wisconsin, Madison, "Interacting particle systems and moving fronts", February 16, 1994.

Jim Coykendall, Cornell University, "Tarski's problem: The elementary theory of the nonabelian free group, February 17, 1994.

Sergi Kunetsov, Cornell Visitor, "Limit theorems for Markov snakes", February 21, 1994.

Jozef Dodziuk, CUNY, "Spectra of hyperbolic manifolds", February 22, 1994.

Harry Kesten, Cornell University, "Branching random walk with a critical branching part, February 28, 1994.

Bakhadyr Khoussainov, MSI, An example of an algebraic but no program categorical model", March 3, 1994

Clara Chan, IDA, Princeton, "Some combinatorics of shellable complexes", March 7, 1994.

Keith Saints, ACSyAM/MSI, Algebraic-Geometric Codes and Multi-dimensional Cyclic Codes: A Unified Theory", March 10, 1994.

Sorin Popescu, Saarbrucken, MSI visitor, "The construction of smooth surfaces in P4 and 3-folds in P5", March 17, 1994.

John Little, ACSyAM/MSI, Systematic Encoding via Groebner Bases for a Class of Algebraic Geometric Goppa Codes, March 17, 1994.

Qi Chen, Cornell University, "McNaughton games", March 17, 1994

Roberto Schonman, UCLA, "Droplet-driven relaxation of stochastic Ising models", March 28, 1994.

Oscar Moreno, M/EPSCOR, University of Puerto Rico, "Costas Arrays and Some Conjectures on Permutation Polynomials", March 31, 1994.

Garrel Pottinger, MSI, "What a model of the whole Lambda calculus really is", March 31, 1994.

Sungchul Lee, Cornell University, "Greedy lattice animals, April 4, 1994.

Vygantas Paulauskas, Cornell visitor, "Central limit theorem in Banach spaces and some problems of functional analysis", April 5, 1994.

Richard Lawson, ACSyAM/MSI visitor, "Trees and Differential Operators", April 7, 1994.

Itai Banjamini, MSI, "Percolation on hyperbolic graphs," April 11, 1994.

Chris Heegard, Cornell University, "Uniform Partitions of Group Codes", April 12, 1994.

Ronitt Rubinfeld, ACSyAM/MSI, "Robust Characterizations of Polynomilas with Applications to Program Testing"", April 14, 1994.

David Aldous, University of California at Berkeley, "Recursive self-similarity for random trees, random triangulations and Brownian excursion", April 18, 1994.

Pete McMullen, University College at London, "Face vectors of simple convex polytopes", April 19, 1994.

Audrey Ferry, Kentucky, "Topoligical characterizations for logic programming semantics", April 21, 1994.

Jesus De Loera, ACSyAM/MSI, "Computing Regular Triangulations of Point Configurations", April 21, 1994.

Wenzhang Huang, MSI, "Square Wave and Transition Layer for a Singularly Perturbed System of Differential-Difference Equations:", April 27, 1994.

John Little, ACSyAM/MSI, "Counting solutions of polynomial equations over finite fields", April 28, 1994

Peter Cholak, Cornell University visitor, "On the Elementary Theory of the Lattice of Recursively Enumerable Sets", April 28, 1994.

Peter Cholak, Cornell University visitor, "On the Elementary Theory of the Lattics of Recursively Enumerable Sets II", May 5, 1994.

Jim Coykendall, ACSyAM/MSI visiotr, "Normsets and Factorization in Rings of Integers", May 5, 1994.

Rick Palmer, ACSyAM/MSI visitor, "Algebraic Topology as a language for computing", June 2, 1994.

Dexter Kozen, ACSyAM/MSI, "Resolution of Singularities of Plane Curves", June 9, 1994.

G. Michler, ACSyAM/MSI visitor, "On Algorithms for Parallel Group Computations", June 14, 1994.

Alexander Barvinok, ACSyAM/MSI, "(Sparse) interpolation of symmetric polynomials and computations in the representation ring of the symmetric group", June 16, 1994.

Workshops and Seminars July 1, 1994-December 31, 1994

Computational Geometry, October 14-15, 1994

Women In Probability, October 16-18, 1994

Hybrid Systems and Autonomous Control, October 28-30, 1994

International Logic Programming Symposium, November 14-17, 1994

Seminars

Sergei Goncharov, Novosibirsk University, "Families of r.e. sets with unique computable enumerations", November 10, 1994.

Rick Durrett, Cornell University,"Interface problems", November 14, 1994.

Howard Blair, Syracuse University, "The closed world assumption", November 15, 1994.

Zhen-Qing Chen, Cornell University, "Probabilistic potential theory for weakly coupled elliptic systems", November 16, 1994.

Paul Chew, Cornell University, "Vornoi diagrams of lines in 3-space", November 17, 1994.

Victor Marek, University of Kentucky, "Revision programming", November 17, 1994.

A. Pisztora, Courant Institute, "Surface order large deviations for the Ising model and percolation in 3 or more dimensions", November 21, 1994.

Sungchul Lee, Cornell University, "The central limit theorem for minimal spanning trees", November 28, 1994.

Workshops and Seminars January 1, 1995-June 30, 1995

Qi Chen, Cornell, "Resursive chattering lemma", February 9, 1995

Jennifer Davoren, Cornell, "Extracting finite automata for hybrid systems", February 16, 1995.

Robert Milnikel, Cornell, "Modal nonmonotonic logic", February 21, 1995.

David Morrison, Cornell visitor, "Conjectural constructions of mirror manifolds", February 27, 1995.

Andre Nies, Cornell visitor, "Application of coding methods to structures from computability theory, I", March 2, 1995.

Andre Nies, Cornell visitor, "Application of coding methods to structures from computability theory, II", March 9, 1995.

Bakhydar Khoussainov, MSI/Cornell, "Presentations, reducibilities, and dimensions of recursive models", March 16, 1995.

Leon Harkleroad, Cornell visitor, "Effectivizing combinatorics: variations on Szpilrajn and Dilworth", April 13, 1995.

Peter Kopke, Cornell, "What's decidable about hybrid automata?", April 17, 1995.

Moss Sweedler, Cornell, "The Gersgorin circle theorem", April 18, 1995.

Jennifer Davoren, Cornell, “Three valued nonmonotonic logic”, April 18, 1995.

Ken Alexander, University of Southern Calfiornia, “Qualitative structure of level lines of 2D random fields”, April, 24, 1995.

Nich Shephard-Barron, Cambridge Univ., “Foliations on algebraic varieties”, May 1, 1995.

Andre Nies, Cornell visitor, Coding in the lattics of R.E. sets”, May 4, 1995.

Workshops and Seminars July 1, 1995-December 31, 1996

Anil Nerode, Director of MSI, sponsored Hybrid Systems IV, October 12-14, 1996.